NEW PERMIAN CRINOIDS FROM AUSTRALIA

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New crinoids are described from the Permian of Queensland, New South Wales, Tasmania, and Western Australia. They 1, strengthen affinities with Timor and North America; 2, add to knowledge of biodiversity; 3, improve knowledge of some earlier described taxa; and 4, extend the stratigraphic value of *Neocamptocrinus*.
Range of the Isocrinidae is extended down to the Artinskian, based on *Archaeoisocrinus occiduaustralis* gen. et sp. nov. The new Order Ampelocrinida which is recognised by syzygial brachial pairs in which muscular articulation alternates with cryptosyzygial articulation is assigned to the Articulata and includes the Ampelocrinidae, Corythocrinidae, Calceolispongiidae and Tribrachyocrinidae.
Euspirocrinids are recognised in the Artinskian and possibly Roadian of eastern Australia, extending their range from the Visean. Three flexible crinoids are recognised in the Artinskian of WA.
Cymbiocrinus cherrabunensis is designated the type species of the *Metacalceolispongia* gen. nov. Other new genera and species described are *Inaglyptocrinus willinki*, *Necopinocrinus tycherus* and *Eidosocrinus coudaunensis*. New species described are *Platycrinites halos*, *Auliskocrinus? bauanaensis*, *Neocamptocrinus catherinensis*, *Spaniocrinus geniculatus*, *Glaukosocrinus middalyaensis*, *Pedinocrinus? nodosus*, *Moapacrinus cuneatus* and *Sundacrinus medius*. ☐ *Crinoids, Permian, Queensland, New South Wales, Tasmania, Western Australia.*

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Permian crinoids of Western Australia were reviewed by Webster (1987) and Webster & Jell (1992). Permian crinoids of eastern Australia were reviewed in Webster (1990). Those reviews may be summarised here by noting that the earliest descriptions of Australian crinoids were in 1847, most species have been described since 1949, and that crinoids are widespread in the marginal Permian basins of both eastern and Western Australia.

Paleobiogeography of Australian Permian echinoderms (Webster et al., in press) may be summarised by noting that: 1. Permian echinoderms are common elements in deposits of eastern Australia from Sakmarian into Wordian time and in WA from Sakmarian into Wuchiapingian time; 2. Australian echinoderm faunas are dominated by taxa endemic to Australia and the Tethys, but contain a few taxa found throughout the equatorial belt; 3. Australian faunas show greatest affinity to the faunas of Timor, but contain some North American Carboniferous taxa that are holdovers in Australia or the Tethys; and 4. Australian echinoderms lived in a cooler water, clastic-rich environment of deposition S of 35° S.

The purpose of this paper is to: 1. describe new Permian crinoids from Australia; 2. provide new information on some previously described taxa; 3. relate the new material to previously described faunas; and 4. denote the significance of an Early Permian articulate crinoid in WA.

FAUNAL ANALYSIS

Western Australian crinoids are reported from 5 horizons. This includes previously unreported taxa in 3 horizons, and new information on taxa from the other 2 horizons (Table 2).

The Permian crinoid fauna of the Callytharra Formation is the most diverse in Australia and second largest in the world. Webster & Jell (1992) reported 16 camerates, 37 inadunates, and 1 flexible, increased here to 42 inadunates (6 disparids, 3 cyathocrinids, and 33 poteriocrinids) and 7 flexibles. Most of the new material consists of disarticulated radial plates and fragmentary sets of arms. The 3 species each of *Prophyllocrinus* and *Loxocrinus*, and the arms of a timorechinid show increased affinity of Callytharra and Timor (especially Basleo) faunas. This supports proposed correlation of the Callytharra fauna with part of the Basleo fauna and an Artinskian age for that part of the Basleo faunas (Webster, 1987; Webster & Jell, 1992).

Glaukosocrinus in the Callytharra fauna is its first report outside North America, extending the range from the Late Carboniferous into the Permian.

A crown of *Archaeoisocrinus occidaustralis* gen. et sp. nov., found in the arms of a crown of *Jimbacrinus bostocki*, from the Cundlego Formation on Jimba Jimba Station is the earliest known articulate crinoid. The articulate crinoids were previously known from the Early Triassic to the Recent, thus their range is extended into the Palaeozoic approximately 28 m.y.

The Wandagee Sandstone yielded an abundance of loose columnals of several species of *Calceolispongia*, whereas articulated cups and crowns are rare. No new taxa are described from the Wandagee, but details of *C. abundans* and *C. rubra* suggest that all calceolispongiids: 1, lived either resting on or partly buried within the substrate, with the stem serving as a runner or vestigial tether in the adult stages; 2, had syzygial articulation facilitating differential movement between laterally adjacent 1st and 2nd brachials of each ray; and 3, that together, the 1st and 2nd brachials of all rays formed a facultative tegmen capable of gentle expansion and contraction, as needed for capacity adjustment of the gut tract.

Discovery of an in situ nest and its partly weathered components consisting of several crowns, partial crowns, and fragments of *Neocamptocrinus millyitensis* in the Cherrabun Member of the Hardman Formation provides new information on the arms, and proximal and medial stem of this Wuchiapingian camerate.

Crinoids of eastern Australia are described from 7 stratigraphic units from early Artinskian to Wordian. This includes new taxa from 5 of the units and new information on taxa from 2.

A reconstructed cup and proximal brachials of *Calceolispongia gerthi* from the Sakmarian Berridale Limestone of SE Tasmania has a cylindrical shape that rested on the substrate probably attached by a runner type stem. This supports the interpretation as discussed for *C. abundans* and *C. rubra*.

Pentastellate columnals and disarticulated cup plates of *Nowracrinus ornatus* from the early Artinskian Kansas Beds of NW Tasmania are recognised in the lineage of the early articulate crinoids. Columnals have a crenularium that parallels the stellate outline and nodals have 5 elliptical cirral facets.

Neocamptocrinus catherinensis sp. nov. is the first report of the genus from the late Artinskian Catherine Sandstone. *Gissocrinus*? sp. (=*Anaglyptocrinus* sp. herein) was the only crinoid previously reported from the Catherine Sandstone (Willink, 1979b). These two genera are Tethyan and Australian endemics, respectively.

The discovery of *Anaglyptocrinus willinki* in the Wandrawandian Siltstone enlarges that fauna to 12 species in 7 genera. The Wandrawandian Siltstone, with the second largest Permian crinoid fauna in E Australia, contains *Calceolispongia* (3 spp), *Neocamptocrinus* (2 spp), *Notiocatillocrinus* (2 spp) and *Tribrachyocrinus* (2 spp). The Wandrawandian fauna could be referred to as an Australian fauna with Australian endemics *Notiocatillocrinus*, *Nowracrinus*, *Tribrachyocrinus* and *Anaglyptocrinus* and Tethyan endemics *Neocamptocrinus* and *Calceolispongia*; only *Dichocrinus* is found throughout the equatorial belt in the Carboniferous and appears to be a Permian holdover in Australia. *Notiocatillocrinus*, *Neocamptocrinus* and *Calceolispongia* show affinity with the Callytharra Formation and suggest an Artinskian age. The Wandrawandian fauna is in situ, as many specimens retain stem and arms attached and associated brachiopods and corals are in living positions suggesting they lived below storm wave base. Shi & McLoughlin (1997) considered the Wandrawandian Siltstone to represent an offshore environment on an unstable palaeoslope.

For the first time crinoids are reported from the latest Artinskian Condamine Beds of SE Queensland. The Condamine fauna is the most diverse known from E Australia, contains several very large specimens, and is not typical of other Permian faunas of E Australia. It shows affinity with the Basleo faunas of Timor containing *Neocamptocrinus*, *Platycrinites*, *Spaniocrinus*, and *Sundacrinus* in common. It also shows affinity with the Wandagee Sandstone, with *Eoindocrinus praecontignatus* in common, which supports a late Artinskian age for the Condamine Beds. Occurrence of *Calceolispongia* sp. shows affinity with E and W Australian faunas. Other identified elements in the fauna are *Necopinocrinus tycherus* gen. et sp. nov., the youngest known cuspiocrinid, and *Moapacrinus cuneatus* sp. nov., perhaps the youngest known cromyocrinid and showing affinity with Artinskian faunas of North America.

Two interesting elements of the Condamine fauna are sets of arms questionably assigned to a stellarocrinid and an indeterminate poteriocrinid. Both have brachials considerably larger than in most Palaeozoic crinoids. The stellarocrinid(?) arms are unusual, with the pinnules attached to the shorter end and a large protruded node on the longer end of each brachial. Large nodes on the inner side of the brachial are unknown in the crinoids and the pinnules are normally attached to the longer end of the brachial. The nodes would have served as protection for food particles moving along the ambulacral trackway in the wide ambulacral groove in the open feeding posture. Development of the pinnule on the shorter end of the brachial may be a result of enlargement of the longer end to accomodate the prominent node. Brachials of Poteriocrinid indet., arm fragment 1, are the first pseudobiserial reported. They are also bipinnulate and apparently represent a terminal late Palaeozoic evolutionary development.

The Condamine fauna is judged to be near in situ, with several specimens retaining arms and proximal stem. Specimens probably represent storm kills transported a short distance and buried in a silty mud.

Auliskocrinus? *bananaensis* and a tribrachyocrinid(?) arm fragment from the Wordian Flat Top Formation of central E Queensland are associated with starfish and plant fragments. These are the first crinoids reported from the Flat Top Formation, increase the number of crinoids found in a sandstone matrix and are interpreted as living in a clastic environment.

There are 120 species of Permian crinoids recognised in WA (Teichert, 1949, 1954; Webster, 1987, 1990; Webster & Jell, 1992, herein). However, only 55 (45.8%) are identified species, or referred (cf.) to a named species. All others are referred to generic or higher taxonomic categories and are represented by partial cups or crowns, sets of arms, arm fragments, loose radials, and rarely columnals. In E Australia 60 species of Permian crinoids are recognised (Willink, 1978, 1979a, 1979b, 1980a, 1980b; Webster, 1990; herein). Of these, 49 (81.7%) are identified to, or referred (cf.) to species level. All others are identified like the WA taxa and represented by similar types of incomplete specimens. Among the E and W Australian taxa there are several that merit special comment.

The Dichocrinidae were common in the Early Carboniferous and rare in Late Carboniferous of North America and Europe (Broadhead, 1981; Webster, unpublished compilation). In the Permian they are unknown outside the Tethys, where they are moderately common, especially in Australia. *Neocamptocrinus* is of stratigraphic utility in both E and W Australia, although after introduction to Australia lineages may have evolved independently in the two regions. *Neocamptocrinus catherinensis* sp. nov. in the Catherine Sandstone and *N*. sp. in the Condamine Beds increase the stratigraphic utility of the genus. Reports of the stems of *Camptocrinus* (=*Neocamptocrinus*) in Russia (Yakovlev, 1956) and Timor (Wanner, 1924) show the widespread distribution of the genus in the Tethys and suggest its utility for correlation therein.

Calceolispongia and *Jimbacrinus* are widespread in the Permian of Australia and the former is known (as *Dinotocrinus*) from Timor (Wanner, 1916, 1924, 1937) and India (Reed, 1928, 1933). Their stratigraphic utility in Australia has been reported by Teichert (1949), Willink (1979b), and Webster & Jell (1992). *Calceolispongia* is considered to have evolved as 2 separate lineages in E and W Australia in the Early Permian (Willink, 1979b; Webster & Jell, 1992).

Neocamptocrinus commonly occurs with *Calceolispongia*. These 2 genera had similar, widely tolerant, ecological requirements as reflected in their ability to live in either clastic or carbonate depositional environments. Both taxa were lower level feeders, living attached to runner stems, or in some species of *Calceolispongia* tethered by a dysfunctional stem in the adult stages. When in association, *Calceolispongia* is typically more abundant, *Neocamptocrinus* has a greater stratigraphic range, extending into the Wuchiapingian.

Platycrinites (Late Devonian into Late Permian) is one of the few long ranging crinoid genera of the Paleozoic. It also had widely tolerant ecological requirements as it is found in the claystones, marls, and arenaceous limestones of the Callytharra Formation and the mudstones of the Condamine Formation. It is one of the few equatorial genera in the Permian and a higher level trophic feeder.

Euspirocrinids were reported to have a range of Middle Ordovician, Mohawkian, to Early Carboniferous, Tournaisian, by Lane & Moore (in Moore & Teichert, 1978). The discovery of *Anaglyptocrinus willinki* gen. et sp. nov. in the Wandrawandian Siltstone at Warden Head, NSW, and *Necopinocrinus tycherus* gen. et sp. nov. in the Condamine Beds, extends the range of the family into the late Artinskian and possibly early Roadian.

Webster et al. (in press) recognised 37 Permian crinoid genera in Australia. Of these: 34 were based on cups and crowns and identified to genus; 2 genera were based on stems; and 1 was referred to as Rhenocrinidae n. gen. In this study, 11 genera are reported for the first time from Australia. These are: *Auliskocrinus*?, *Anaglyptocrinus*, *Necopinocrinus*, *Eidosocrinus*, *Archaeoisocrinus*, *Spaniocrinus*, *Glaukosocrinus*, *Pedinocrinus*?, *Sundacrinus*, *Moapacrinus*, *Loxocrinus* and *Prophyllocrinus*. In addition, 9 indeterminate genera, that are probably new for Australia, are based on poorly preserved crowns, cups, sets of arms, arm fragments and loose cup ossicles. Together these bring the total number of Permian crinoid genera for Australia to 56, with *Anaglyptocrinus* replacing *Gissocrinus*? of Willink (1979a). Of the 46 named genera 14 (30.4%) are endemic to Australia, 13 (28.3%) are endemic to the Tethys, 7 (15.2%) are found throughout the equatorial belt, and the other 12 (26.1%) are Permian holdovers in Australia or known from Australia and one other locality outside the Tethys, but at this time, not considered to be cosmopolitan. Bambach (1990) pointed out that there are no true cosmopolitan crinoid taxa in the Permian, since no taxon is found in all four of the biogeographical regions he recognised. Genera referred to as cosmopolitan by Webster et al. (in press) are found throughout the equatorial latitudes and the cooler water higher latitude Australian localities.

Eastern Australian crinoid faunas contain 8 endemic genera whereas WA faunas contain 3. In addition there are 3 Australian endemics common to both. Undoubtedly, there will be additional endemics recognised as more complete specimens of indeterminate taxa are found. These taxa represent evolution in cooler water, clastic-rich environments, not the equatorial belt carbonate rich environments typical of most Palaeozoic crinoid faunas. We suggest that the E Australian endemic genera will continue to be a greater number than those of WA. Western Australian taxa currently identified as genus, family, and order indeterminate will probably contain a good percentage of taxa described from Timor. Eastern Australian faunas have less affinity with Timor and evolved in latitudes farther S than those of WA (Webster et al., in press).

AGES AND CORRELATION

The Permian stratigraphy of Western Australia was correlated internationally on moderately frequent occurrences of ammonoids (Glenister et al., 1993). Few Permian ammonoids have been reported from E Australia so there the regional biostratigraphy is based on brachiopods (Dickins et al., 1964, among others). International correlations of some Permian units of E Australia are not clear (Day et al., 1975).

Eastern and Western Australian crinoid faunas have in common *Dichocrinus*, *Neocamptocrinus*, *Platycrinites*, *Notiocatillocrinus*, *Eoindocrinus*, *Calceolispongia*, and possibly *Jimbacrinus*. Only *E. praecontignatus* is common at species level. The Wandagee Sandstone of WA is late Artinskian (Glenister et al., 1993) and is correlated using *E. praecontignatus* with the Condamine Beds of SE Queensland. An Artinskian age for the Condamine Beds is supported by *Moapacrinus* which is Artinskian in North America (Webster & Lane, 1967).

Occurrence of crinoid genera and species in E and W Australia implies that both regions were connected by seaways in the late Sakmarian to allow the incursion of *Calceolispongia*. In the latest Sakmarian or early Artinskian *Neocamptocrinus* and *Notiocatillocrinus* invaded both areas. In the middle Artinskian *Jimbacrinus* and *Dichocrinus* are common to both regions. *Platycrinites* and *Eoindocrinus praecontignatus* are found in both areas in the late Artinskian. This implies that E and W Australia were interconnected repeatedly in the Early Permian. Because the lineages of *Calceolispongia* and *Neocamptocrinus* are apparently separate in E and W Australia, it would appear that there was a common source for both areas, but not an interconnection for two-way exchange between them.

At the generic and specific level WA faunas correlate most closely with the Basleo faunas of Timor. *Loxocrinus booni*, 2 other species of *Loxocrinus*, and 3 species of *Prophyllocrinus* in the Callytharra Formation support the suggestion (Webster & Jell, 1992) that part of the faunas of the Basleo Beds are of Artinskian age. *Spaniocrinus* and *Sundacrinus* in the Condamine Beds show affinity with the Basleo Beds and support an Artinskian age. All other faunas of E Australia show little affinity with the Basleo Beds, except for the longer ranging, Tethyan endemics *Calceolispongia* and *Neocamptocrinus*.

STEM ARTICULATA

Discovery of *Archaeoisocrinus* gen.nov. in the Artinskian of Western Australia requires a review of characteristics defining the subclass Articulata. Simms (1988) defined the Articulata on a combination of morphological characters, but most significantly on the absence of the anal plate in the cup. He pointed out that all of the morphological characters recognised in the Articulata were individually or in various incomplete combinations known in various Palaeozoic taxa, but not in the total combination as found in the post-Palaeozoic articulates.

Simms & Sevastopulo (1993) reviewed the origin of the articulate crinoids, noting that, as defined by Miller (1821), a number of late Palaeozoic crinoids could be included in the Articulata. Furthermore, applying a cladistic study of 9 primitive and derived morphologic characters (Simms & Sevastopulo, 1993, text-fig 2), they compared 3 Middle Triassic articulate genera to 11 Palaeozoic taxa which have been proposed as ancestral, or have close morphological affinities, to the articulates. They also suggested a revised classification of the Palaeozoic crinoids that included major revisions of, as well as supression of the term, Inadunata. We agree with most of the proposed clades of Simms & Sevastopulo (1993), but do not agree, with excluding their middle to late Palaeozoic 'stem-group articulates' from the Articulata. They referred to the post-Palaeozoic Articulata as the 'crown-group articulates'. This makes the Articulata a horizontally defined (Simpson, 1961) taxon. Simms & Sevastopulo (1993) justified the new definition of the Articulata by adding the recognition of the entoneural system enclosed within the thecal plates.

Simms & Sevastopulo (1993) noted several late Palaeozoic crinoids with the entoneural system enclosed within thecal plates. However, all of the Palaeozoic taxa that they discussed had one or more anal plates within the cup, and thus could be excluded from the crown-group articulates or Articulata, following the definition of Simms (1988) in combination with the entoneural system enclosed within thecal plates.

We assert that the synapomorphic feature that defines the Articulata is the development in the arms of syzygial brachial pairs in which muscular articulation alternates with cryptosyzygial ligamentary articulation as illustrated by Willink (1979b, text-fig. 16) for *Meganotocrinus*. We also conclude that brachial morphology described as rectilinear, weakly cuneate, moderately cuneate, strongly cuneate, cuneate biserial and rectilinear biserial may be considered an evolutionary lineage. However, such evolution could and did stop anywhere along this sequence within different crinoid lineages. Thus the 2 states of uniserial (= primitive) and biserial (= derived) arms, as given by Simms & Sevastopulo (1993, text-fig. 2), are insufficient for defining the complex brachial morphology. We agree that biserial arms evolved more than once in the Palaeozoic, once in the Mesozoic, and that they provided greater flexibility of the feeding arm. We also assume that biseriality became a dead-end. We suggest that the reason biseriality was a deadend may be that the interior axial canals could not function efficiently in the short zigzag relationship between adjacent brachials in the cuneate and rectilinear biserial conditions, if it ever developed in those forms. Development of the interior axial canals in the cuneate brachials provided greater protection from injury to the canals in the development of muscles at articular facets, at points of arm branching and on the facets of syzygial paired brachials. They were not restricted by short spaces between zigzag facets. Removal of the anal from the cup was an evolutionary trend that was repeated many times throughout the Palaeozoic. The loss of the anals from the cup in the stem-group articulates is considered unrelated to the development of the entoneural system being enclosed in thecal plates, as some genera (*Calceolispongia*, among others) developed an entoneural system enclosed in thecal plates while retaining an anal within the cup.

We agree with Simms & Sevastopulo (1993) that: 1) the Ampelocrinidae and Cymbiocrinidae should be combined and revised; 2) they contain genera that are not stem-group articulates and should not be included within the family; 3) several taxa of stem-group articulates are insufficiently defined to fully evaluate their position in the lineage; 4) Articulata, as here defined, is a monophyletic clade.

We propose that the primitive Articulata possessed the following morphologic features: 1, dicyclic or cryptodicyclic cup; 2, cirri with multiradiate articula distally and transverse ridge articula proximally or cirri with transverse ridge articula throughout; 3, pinnulate arms; 4, brachial articula with ligamentary and clearly defined muscular fossae; 5, first arm division on primibrachs 2-4; 6, entoneural system enclosed in paired canal; 7, syzygial brachial pairs in arms; 8, anals in cup, 1 to 3; and 9, uniserial arms, with cuneate brachials. These morphologic features are found in *Chlidonocrinus*, *Ampelocrinus*, and *Nowracrinus* as shown by Simms & Sevastopulo (1993, text-fig 2), but they included these taxa in their stem-group articulates. It should also be noted that each has a pentagonal stem proximally.

TABLE 1. Comparison of major morphologic characters of genera assigned to the Order Ampelocrinida and isocrinid *Archaeoisocrinus*.

Family and Genus	Cup Shape	No. Anals	No. IBr	No. Arms	Pinnules/ Ramules	Stem X-sect at cup	Cirrate at cup	Anal Sac	Facet Type
Corythocrinidae									
Corythocrinus	conical	1	3	20-30	pinnulate	round	no	?	plenary
Araeocrinus	conical	3	4-5	20+	pinnulate	round	?	long	plenary
Campbellicrinus	conical	1	3	12	pinnulate	round	?	short	plenary
Ampelocrinidae									
Ampelocrinus	med bowl	3	2	10	pinnulate	pentag	yes	recurved	plenary
Chlidonocrinus	med bowl	1	2	20 min	pinnulate	pentag	yes	?	plenary
Cymbiocrinus	low bowl	1	2	10	pinnulate	pentag or rd	yes	?	plenary
Halogetocrinus	low bowl	1	3-4	10+	pinnulate	round	yes	?	plenary
Moundocrinus	med bowl	1	2	10	pinnulate	subpentag	?	short	plenary
Oklahomacrinus	discoid	1	2	10	pinnulate	subpentag	?	?	plenary
Calceolispongiidae									
Allosocrinus	med bowl	1	-	5	pinnulate	subpen to rd	?	?	plenary
Calceolispongia	high bowl	1	-	5	pinnulate	subpen to rd	yes	?	plenary
Jimbacrinus	high bowl	1	-	5	pinnulate	subpen to rd	no	?	plenary
Metacalceolispongia	med bowl	1	2	11+?	pinnulate	pentag	?	?	plenary
Tribrachyocrinidae									
Tribrachyocrinus	globe	3-4	2	12 min	ramules	round	no	short	plenary
Meganotocrinus	globe	1	2	20	ramules	round	no	short	plenary
Nowracrinus	globe	1	2	20	ramules	round	yes	short	plenary
Insertae sedis									
Tasmanocrinus	conical	0 or 1?	2	6 min	pinnulate	pentag	yes	short	peneplenary
Isocrinidae									
Archaeoisocrinus	discoid	0	2	10	pinnulate	pentag	?	?	plenary

We consider *Corythocrinus*, from the late Tournaisian of Indiana (Tables 1, 2), the oldest Articulata. This is followed, in order of earliest occurrence, by *Chlidonocrinus*, *Cymbiocrinus* and *Ampelocrinus*, from the Visean of North America. We consider the report of *Ampelocrinus* from the Visean of England (Wright, 1951) a questionable identification. Offshoots of the Ampelocrinidae include the Calceolispongiidae, a Late Carboniferous–Permian lineage, and Tribrachyocrinidae, a Permian lineage. Thus, our higher level classification is:

Subclass Articulata
Order Ampelocrinida ord. nov.
Order Millericrinida
Order Cyrtocrinida
Order Bourgueticrinida
Order Isocrinida - with *Archaeoisocrinus* gen. nov.
Order Comatulida
Order Uintacrinida
Order Roveacrinida

Origin of the Ampelocrinida is uncertain. Strimple & Watkins (1969) suggested that *Corythocrinus* was derived from a rhenocrinid because the plicate plates of the anal tube indicated affinities between these two forms; however, plicate tube plates are also known in poteriocrinitids and are common among dendrocrinids. Moore & Teichert (1978) considered the Ampelocrinidae derived from the Decadocrinidae, but gave no explicit reasons for supporting this relationship. Because so many stem articulates have 1 anal, we suggest that the Ampelocrinida might be derived from a cyathocrininid, such as *Lecythocrinus*, where the radianal had already been eliminated from the cup, or *Corynecrinus*, where the radianal and anal X are above the posterior basal. However, the 3 anals in *Ampelocrinus* and *Araeocrinus* suggest that the presence of a single anal may not be a primitive character of the group. Carboniferous evolution of the Ampelocrinida occurred in North America and Europe, whereas the Permian record is within the Tethys, especially E Australia, except for North American species of *Halogetocrinus* and *Allosocrinus* (Table 2).

Moore & Jeffords (1968) described several taxa with pentagonal and pentastellate columnals from Devonian and Carboniferous strata of the United States. The cups are either unknown or not recognised in association with the columnals. The geographic distribution of such

TABLE 2. Range chart of genera assigned to the Ampelocrinida. (x) indicates age of type species. (—) indicates age of species assigned to the genus. United States series names used for Carboniferous because known record is restricted to North America.

Family & Genus	Carboniferous (part)								Permian (part)						
	Osag.	Mrmc.	Chst.	Morw.	Atok.	Dsmn.	Mssr.	Vrgl.	Assl.	Skmr.	Artk.	Road.	Word.	Capt.	Wuch.
Corythocrinidae															
Corythocrinus	x														
Araeocrinus					x										
Campbellicrinus										x					
Ampelocrinidae															
Ampelocrinus			x	—											
Chlidonocrinus		—	x			—									
Cymbiocrinus		x	—	—											
Halogetocrinus					—		x	—	—						
Moundocrinus					—		x	—							
Oklahomacrinus					—	—	—	x							
Calceolispongiidae															
Allosocrinus						—	x	—	—						
Calceolispongia										—	x	—			
Jimbacrinus										—	x				
Metacalceolispongia														x	
Tribrachyocrinidae															
Tribrachyocrinus										—	x	—			
Meganotocrinus											x				
Nowracrinus											x				
Incertae sedis															
Tasmanocrinus										x					

columnals is unknown. We suggest that such forms should be investigated as possible stem articulates.

SYSTEMATIC PALAEONTOLOGY

Crinoid teminology follows Ubaghs et al. (in Moore & Teichert, 1978), with columnal patterns after Webster (1974). Measurements are given as: length, parallel to the central axis; width, transverse to, but never cutting or joining the central axis; and depth, normal to, and may join the central axis. Curvature of the cup walls, plate circlets within the cup and fixed brachials are referred as: incurved if distally bending toward, vertical if parallel to, weakly to strongly flaring if bending away from and horizontal if perpendicular to the central axis.

Material collected by us came from localities entered in the Queenland Museum Locality Register (QML), and is curated in the Queensland Museum Palaeontological Collection (QMF). Other palaeontological collections referred to are indicated by the following prefixes: Geological Survey of Queensland, Brisbane (GSQ); Geological Survey of Western Australia, Perth (GSWA); Geological Survey of New South Wales, Lidcombe (MM); Department of Geology, University of Queensland, (UQ); The Natural History Museum London (BME); and Tasmanian Museum (TM).

Subclass CAMERATA Wachsmuth & Springer, 1885
Order MONOBATHRIDA Moore & Laudon, 1943
Superfamily HEXACRINITOIDEA Wachsmuth & Springer, 1885
Family DICHOCRINIDAE Miller, 1889
Subfamily DICHOCRININAE Miller, 1889

Dichocrinus Münster, 1839

TYPE SPECIES. *Dichocrinus radiatus* Münster, 1839 from the Early Carboniferous of Belgium; by monotypy.

Dichocrinus? sp.
(Fig.1B)

MATERIAL. GSWAF50172, from GSWAL119377, Billidee Formation, Artinskian.

DESCRIPTION. Crown small, 29.4mm long (incomplete), 25.8mm wide (arms flared). Cup elongate, cylindrical, unornamented. Basal circlet unknown. D radial 7.7mm long, 3.5mm wide (incomplete), gently convex longitudinally and transversely, with narrow shoulders sloping abmedial. Radial facet angustary, rounded aborally. Anal large, 7.4mm long, 4.6mm wide, widest at base, tapering distally, in line with radials. Arms 2 per ray, isotomous branching on 2nd primibrach, biserial above secundibrach 4-7. Brachials cuneate, moderately convex longitudinally, strongly convex transversely. One slender pinnule per brachial on long side. Stem and tegmen unknown.

REMARKS. This is the first unornamented *Dichocrinus* reported from the Permian of Australia. Several species of *Dichocrinus* from the Early Carboniferous of the United States have a distally tapering anal plate and most have 10 arms (Broadhead, 1981). The 10 arms are a primitive condition in the genus. Lacking the tegmen, the generic assignment is questioned. The Billidee Formation specimen probably represents a new species, but lacking the basal circlet and tegmen, it is left in open nomenclature.

Auliskocrinus Broadhead, 1981

TYPE SPECIES. *Dichocrinus crassitestus* White, 1862 from the late Tournaisian upper part of the Burlington Limestone, Iowa; by original designation.

Auliskocrinus? bananaensis sp. nov.
(Fig.1A)

ETYMOLOGY. From Banana in central Queensland.

MATERIAL. HOLOTYPE: QMF38897 from QML806.

DIAGNOSIS. Anal tube large, conical, distally tapering above the posterior interradius; cup truncated cone-shaped; basal circlet very short; brachials rectilinear.

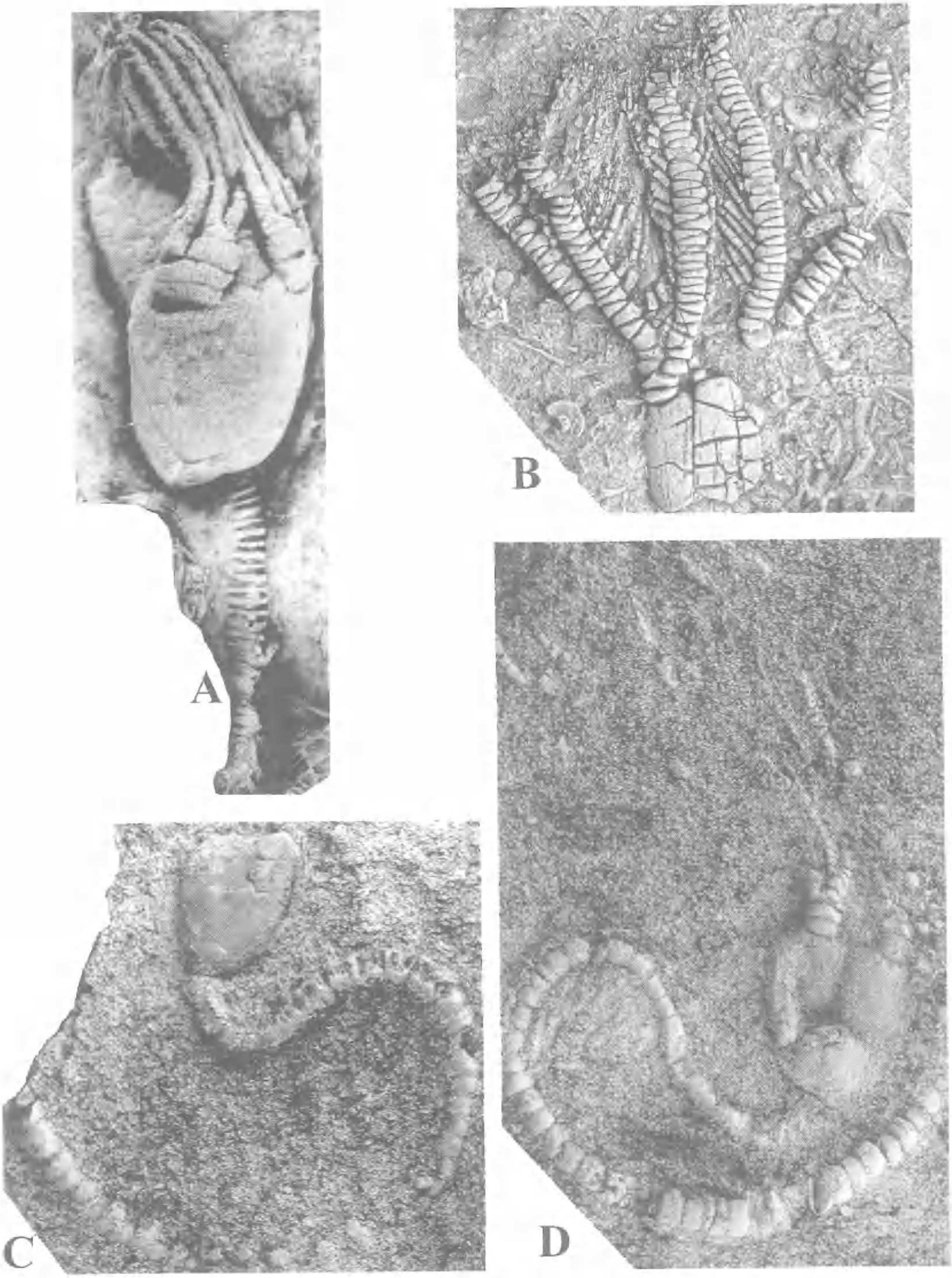
DESCRIPTION. Specimen small, 26.2mm long. Crown small, cylindrical, 16.1mm long, 8.2mm wide at tip of anal tube. Calyx robust, 12mm long to tip of anal tube. Cup truncated conical, 7.4mm long, 6.9mm wide at radial summit; plates smooth; sutures flush. Basal circlet shallow distally flared bowl, 2mm long, 4.8mm wide. Radials large, 5.9mm long, 5mm wide at base of radial notch, longitudinally moderately convex proximally becoming gently convex distally, moderately convex transversely, forming most of cup wall, subvertical distally. Radial facet angustary, 3mm wide, moderately convex projecting from radial aborally. Single anal large, 6mm long, in radial circlet. Tegmen formed of numerous small plates. Anal tube conical, formed of small irregular polygonal plates, tapering distally, distal opening above posterior interradius. Arms relatively short, 11mm long, slender, 4 per ray, isotomously branching on axillary 2nd primibrach. Brachials rectilinear, wider than long, slightly convex longitudinally, strongly convex transversely, with single pinnule on opposite sides of arm. Primibrach 1 much wider (2.6mm) than long (0.7mm). Axillary primibrach 2 3mm wide, 0.8mm long. Stem round, 1.2mm diameter at cup, 10.1mm preserved, heteromorphic. Noditaxis N1; nodals longer and wider than internodals; latus strongly rounded.

REMARKS. *Auliskocrinus? bananaensis* is preserved as an external mould with the C ray centred.

Arguments could be made for erecting a new genus for *A.? bananaensis* or assigning it to *Dichocrinus*. The cup shape, position and plate structure of the anal tube, and rectilinear brachials of *A.? bananaensis* are atypical of the closely related *Auliskocrinus* and *Dichocrinus*. Cup shape of *Auliskocrinus* is relatively high, subconical or slightly globose whereas *Dichocrinus* is relatively high conical. In both genera the basal circlet forms a significant part of the cup wall. Only *D. dichotomus*, an early Visean species with biserial arms, has a bowl-shaped cup with a low upflaring basal circlet, similar to *A.? bananaensis*. No member of the Dichocrininae (Broadhead,1981, fig. 2) has a conical, distally tapering anal tube projecting above the tegmen over the posterior interradius as in *A.? bananaensis*. The small more centrally located vertical anal tube of *Auliskocrinus* is formed of laterally interlocking columns of hexagonal rather than irregular plates, and the genus has slightly cuneate brachials. The tegmen of *Dichocrinus* is typically low, but may be moderately elevated with the anal opening flush or only slightly projected above the tegmen (Broadhead, 1981). Brachials of *Dichocrinus* are either cuneate or biserial, most commonly rectilinear proximally becoming moderately to strongly cuneate distally. Most advanced species have biserial brachials with 20 arms (Broadhead, 1981). With the exception of the truncated conical cup, 20 arms, and projected anal tube, *A.? bananaensis* retains primitive features of *Dichocrinus*.

Variation in cup shape and tegmen structure of monotypic *Auliskocrinus* is unknown (Broadhead, 1981). We assign this specimen to *Auliskocrinus* because the tegmen forms a high cone with a terminal anal opening and the

FIG. 1. A, *Auliskocrinus? bananaensis* sp. nov., C ray view of crown with tegmen, holotype QMF38897, ×4.3. B, *Dichocrinus?* sp., lateral view of partial crown GSWAF50172, ×2.5. C,D, *Neocamptocrinus catherinensis* sp. nov. C, D-E interray view of partial crown, paratype GSQF13487, ×2.5. D, C ray view of crown, holotype GSQF13486, ×2.5.


A
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rectilinear brachials are more similar to the slightly cuneate brachials of *Auliskocrinus*.

Subfamily CAMPTOCRININAE Broadhead, 1981

Neocamptocrinus Willink, 1980

TYPE SPECIES. *Neocamptocrinus bundanoonensis* Willink, 1980a from the Wordian Berry Formation, NSW; by original designation.

REMARKS. Willink (1980a) defined *Neocamptocrinus* primarily on the distinctive inflated tegmen formed of 5 large orals, and numerous small interambulacral and anal plates. He noted *Neocamptocrinus* as a common element in E Australia, recognised 3 species on the basis of cups, another 7 species on columnals, and considered the genus of potential stratigraphic value. In WA there are 3 species (Webster,1990; Webster & Jell,1992), a pluricolumnal from the Callytharra Formation (Webster, 1987) and very large pluricolumnals in the Wandagee Sandstone (Webster & Jell, 1992).Willink (1980a) considered the coiled elliptical stem typical of *Neocamptocrinus*. Broadhead (1981) noted that the elliptical stem distinguishes the Camptocrininae, whereas Dichocrininae have a round stem. Webster (1987) reported stems of *Camptocrinus* cf. *C. indoaustralicus* (considered *Neocamptocrinus* by Webster & Jell, 1992) to vary from slightly elliptical proximally to elliptical to subrectangular distally. Webster & Jell (1992) noted that the proximal stem of *N. millyitensis* is nearly circular in section, becoming elliptical distally. New material of *N. millyitensis* shows the curvature of the enrolled proximal nearly circular part and the transition from that into the strongly elliptical part (Figs 2A-C; 3A,B; 4C,D).

The range of *Neocamptocrinus* in E Australia is from the Sakmarian, Billop Formation of Tasmania, into the Wordian, Condamine Beds of Queensland. In stratigraphic sequence, species recognised are:

N. sp. nov., Condamine Beds

N. bundanooensis Willink, 1980a, Berry Formation

N. catherinensis sp. nov. Catherine Sandstone

N. wardenensis Willink, 1980a, Wandrawandian Siltstone

ø*N. tasmaniensis* (Sieverts-Doreck, 1942), Crinoidal Zone

N. millerensis Willink, 1980a, Billop Formation

The following columnal (ø) species are considered junior synonyms of ø*N. tasmaniensis*: ø*N.? sievertsae* Willink, 1980a, ø*N.? doreckae* Willink, 1980a, ø*N. bernacchiensis* Willink, 1980a, ø*N.? banksi* Willink, 1980a, and ø*N.?* sp. cf. *N.? tasmaniensis*. These are all from the Crinoidal Zone on Maria Island and represent different parts of the stem of one species.

In general, species of *Neocamptocrinus* are distinguished on cup plate ornamentation, cup plate shape, ornament of tegmen plates, and number of arms. The oldest form known, *N. millerensis*, has a slender high cup with a vermiform ornament, whereas *N. wardenensis* has a lower, more bulbous cup and coarse node and irregular ridge ornament. The plates of *N. catherinensis* sp. nov. are smooth, but the tegmen is a prominent conical projection above the posterior interray. Ornament on *N. bundanoonensis* consists of pits on the cup plates. Cup plates of *N.?* sp. indet. (Willink, 1980a, pl. 4, figs 17-26) probably belong with ø*N. tasmaniensis* from the same stratigraphic unit (Crinoidal Zone). This form would have had a lower cup with a longitudinal trending vermiform ornament.

In WA *Neocamptocrinus* ranges from the late Sakmarian, basal Callytharra Formation, into the Wuchiapingian, Cherrabun Member of the Hardman Formation:

N. millyitensis Webster & Jell, 1992, Cherrabun Member

ø*N.* sp. Webster & Jell, 1992, Wandagee Sandstone

N. occidentalis Webster, 1990, Cundlego Sandstone

N. barrabiddyensis Webster & Jell, 1992, Bulgadoo Shale

ø*N.* sp. Webster, 1987 (as *Camptocrinus* cf. *C. indoaustralicus*), Callytharra Formation

N. barrabiddyensis lacks ornamentation, *N. occidentalis* has fine granular ornament on cup plates, and *N. millyitensis* is smooth but has nodes on some oral plates. All have more globose cup shapes than E Australian species. With 8 arms per ray *N. millyitensis* has the greatest number known for the genus. Most species have 4-7 arms per ray, but some rays of *N. millerensis* may have 2. The general trends in evolution of *Neocamptocrinus* in Australia were to: 1, lower the cup by flattening the basal circlet and shortening the length of the radials and primanal; 2, increase the number of arms per ray; and 3, increase in size. Cup and tegmen are smooth or have ornament of

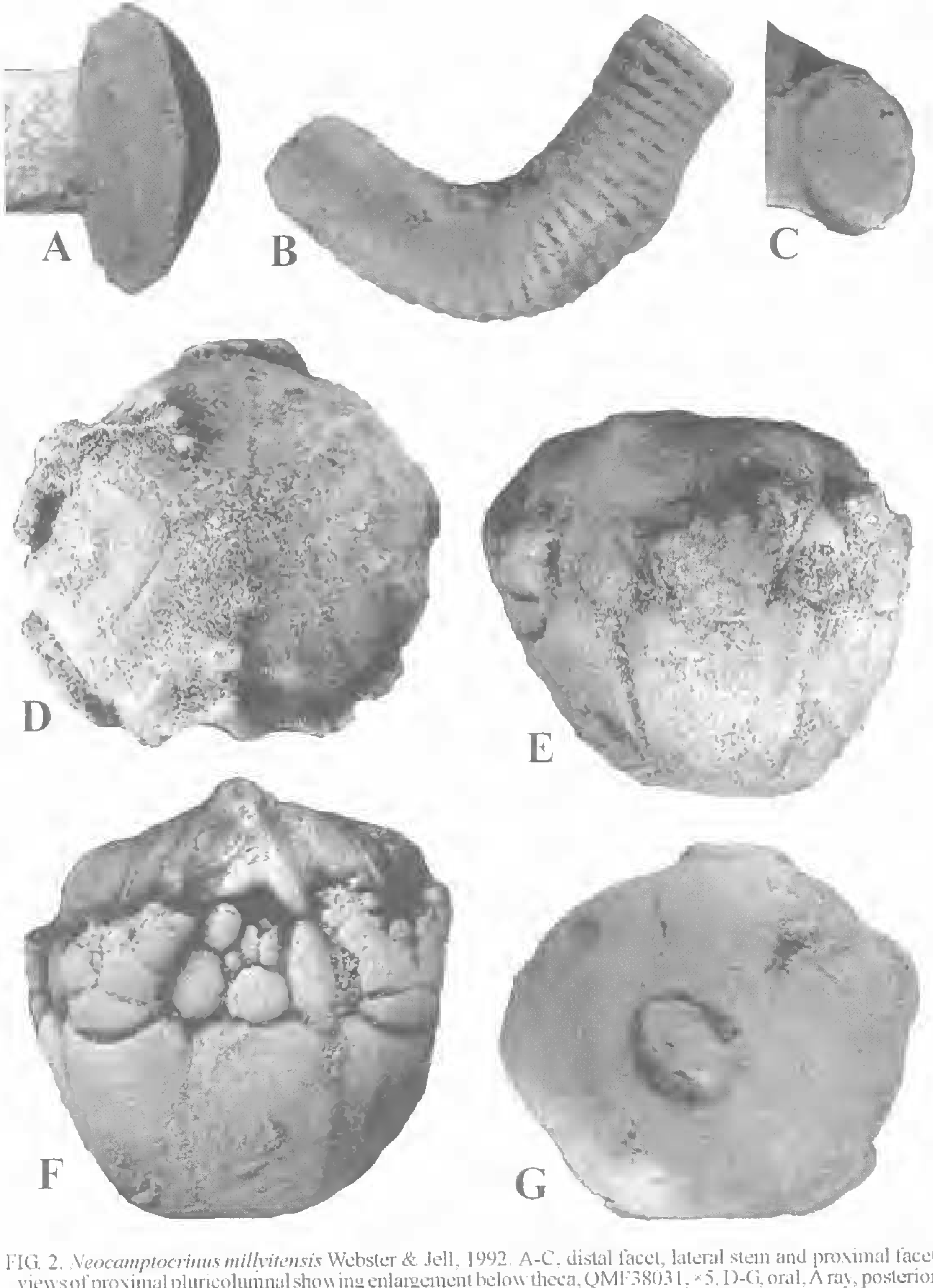


FIG. 2. *Neocamptocrinus millyitensis* Webster & Jell, 1992. A-C, distal facet, lateral stem and proximal facet views of proximal pluricolumnal showing enlargement below theca, QMF38031, ×5. D-G, oral, A ray, posterior and basal views of theca QMF37981, ×2.6.

variable type. *Neocamptocrinus* has the longest stratigraphic range of any Australian Permian crinoid and may have the greatest geographic distribution (columnals referred to as *Camptocrinus* in Timor and Russia are herein considered *Neocamptocrinus*). Only *Calceolispongia* has comparable stratigraphic and palaeogeographic ranges among Australian Permian crinoids.

Neocamptocrinus catherinensis sp. nov.
(Fig.1C,D; Table 3)

ETYMOLOGY. From the Catherine Sandstone.

MATERIAL. HOLOTYPE: GSQF13486 from the Guadalupian, Catherine Sandstone, in the upper part of Sandy Creek, Springwood Homestead, Queensland. PARATYPE: GSQF13487, same.

DIAGNOSIS. Cup small to medium sized, high bowl-shaped; tegmen conical projected toward posterior interray; 4 arms per ray.

DESCRIPTION. Crown small to medium sized, cylindrical. Cup high bowl-shaped, plates unornamented. Basal circlet upflared, 2 equal plates, suture in A-CD plane of symmetry, forming basal one third of cup. Radials 5, heptagonal, gently convex longitudinally and transversely, gently flaring proximally, subvertical distally; distal facets with tegmen plates sloping downward gently. Radial facet angustary, nearly 1/2 radial width, gently rounded below distal tips of radial. Anal plate in radial circlet, gently convex longitudinally and transversely. Arms slender, elongate, 4 per ray, branching isotomously on axillary 1st primibrach and 2nd secundibrach. Brachials rectilinear, uniserial proximally, cuneate, becoming biserial distally. Tegmen with rounded conical projection on posterior. Stem nearly circular proximally becoming strongly elliptical distally, heteromorphic in strongly elliptical part; noditaxis N_{11}. Nodals formed by fused columnals, with incipient cirral scars on outer side.

REMARKS. The holotype is preserved in the enrolled position as original calcite embedded in fine grained sandstone. The cup is crushed with 2 rays and the anal or edge of a 3rd radial exposed. Proximal parts of the arms show the branching pattern and the distal part of the stem is cirrate. Iron oxide replacement of the plates of the paratype is very soft and partly lost on the enrolled proximal part of the stem and partial crown. The uncrushed cup is smaller than the holotype, the D and E rays are centred, the short anal tube projects on the right and the distal part of the preserved stem is cirrate.

TABLE 3. *Neocamptocrinus catherinensis* sp. nov. measurements (mm). *crushed, +estimated.

	holotype GSQF13486	paratype GSQF13487
Crown length, incomplete	26.5	
Calyx length		8.5
Cup length	9.9	6.5
Cup width	10.1*	5.9
Basal circlet diameter	4.8	3.1
Basal circlet length	3.2	1.2
Radial length	5.4+	4.2
Radial width	4.4+	2.4
First primibrachial length	1	
First primibrachial width	2.1	
Proximal columnal diameter	2.1+	1.1
Stem length	65	63.7

The tegmen of other species of *Neocamptocrinus* is inflated and may be slightly elevated towards the posterior side, but is not elevated into a conical projection as sharp or prominent as that of *N. catherinensis*. Only *N. wardenensis* with a rounded posteriorly elevated tegmen is comparable. Also the cup of *N. wardenensis* is a lower bowl shape and the basal circlet is shorter and more outflared. The cup of *N. catherinensis* is most similar to that of *N. millerensis*, which has a very low tegmen and relatively longer radials.

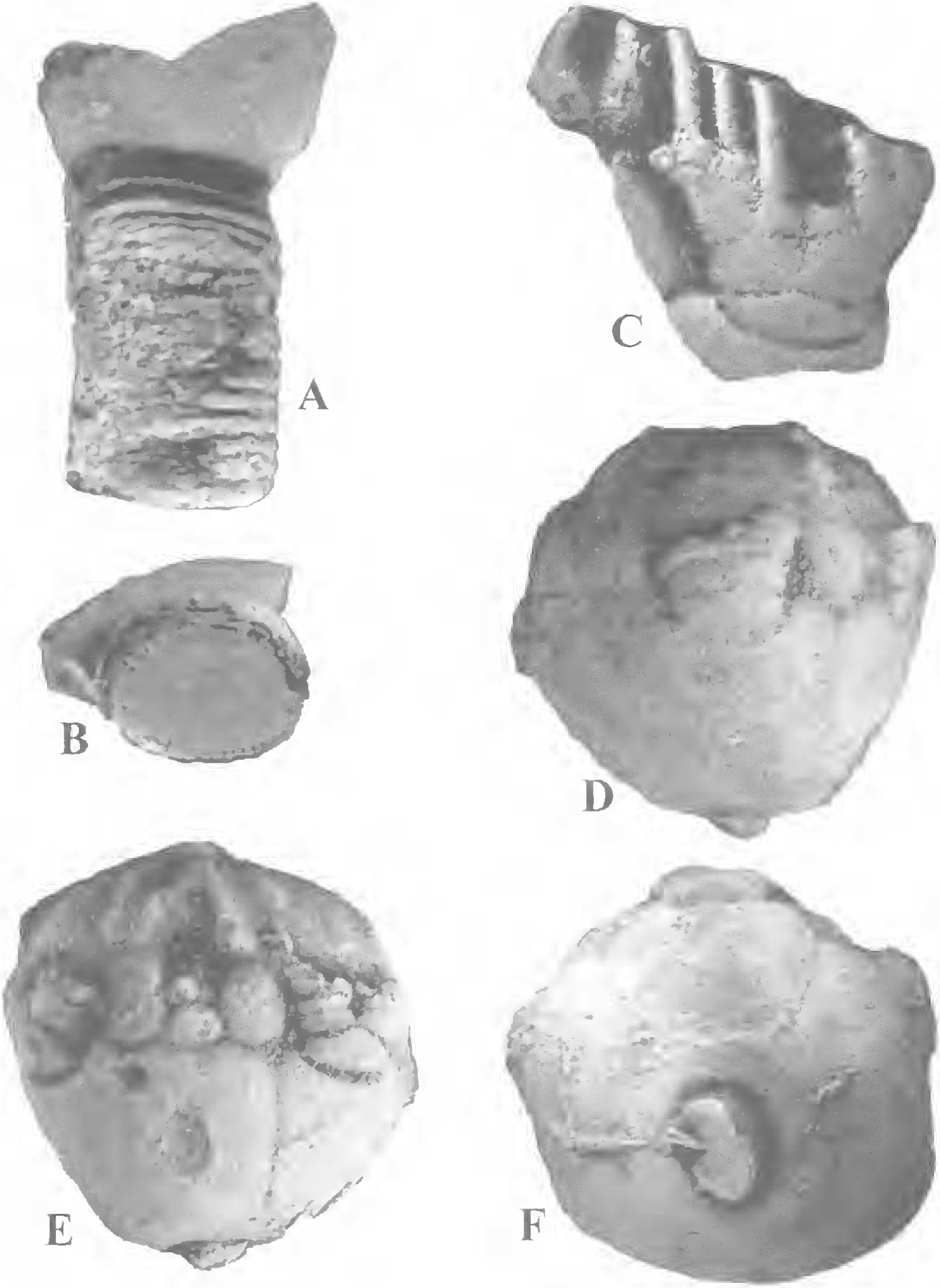
Neocamptocrinus millyitensis
Webster & Jell, 1992
(Figs 2-4)

Neocamptocrinus sp. nov. Webster,1990: 57, pl. 1, figs 7-11.
Neocamptocrinus millyitensis Webster & Jell, 1992: 320, figs 3A-L.

MATERIAL. Crowns QMF37980-F37985, partial calyces (QMF37920, F38986-F38024), partial sets of arms (QMF38025, F38026), radials (QMF37921-F37928), columnals and pluricolumnals (QMF37929-F37971, F38027-F38864), and cirri (QMF37972-F37979, F38865-F38873) from QML772 and 1146).

DESCRIPTION. This description only adds to that of Webster & Jell (1992). Radial facet angustary, approximately half maximum width of radial, sloping outward gently. Brachials cuneate, strongly convex transversely, straight to

FIG. 3. *Neocamptocrinus millyitensis* Webster & Jell, 1992. A,B, lateral and proximal facet views of proximal pluricolumnal and part of basal circlet, QMF38027, ×3.8. C, lateral view of distal end of radial and proximal brachials showing branching pattern, QMF38029, ×4. D-F, A ray, posterior and basal views of theca QMF37980, ×2.6.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E
F

slightly convex longitudinally, deep, uniserial proximally, biserial distally. Arms slender, delicate; endotomous branching heterotomous on single primibrach and secundibrach and isotomous on single tertibrach; arms 40, 8 per ray. Brachials with single slender pinnule (up to 9mm long) on long side. Anal series 3-2, with the 2 plates to the left of the anal opening.

Stem elliptical in transverse section; short, more equidimensional (4.6 × 2.4mm) adjacent to cup; becoming longer, flattened and extended elliptical (10.1 × 3.4mm) within 7-8mm, 2-3cm from the cup; becoming less extended elliptical (9.4 × 6.8mm) an unknown distance distally. Noditaxis pattern heteromorphic, with nodals separated by 2 internodals normally, but varying from 1-3. Cirri attach at ends of ellipse, 2 per nodal; cirral facet extending laterally onto 2 adjacent columnals with growth. Cirri not developed in proximal more equidimensional part of stem.

REMARKS. The revised description is based upon new material listed above. Five of the calyces were in situ in a nest with the broken stem segments in the surrounding matrix. Many of the pluricolumnals are coiled, indicating specimens were enrolled prior to fracturing and disaggregation from compaction and weathering. The calyces and pluricolumnals were encased in a clay to silt and fine sand matrix, rather than the typical fine to medium sand of the Cherrabun Member. This suggests that when enrolled, the cirri formed a protective screen around the crown shielding it from the coarser grained sediments. As burial proceeded, finer grained sediments infiltrated the cirri entombing the crowns. Compaction after burial distorted and fractured some of the calyces and broke the stem into pluricolumnals. Modern weathering left a lag gravel of columnals, pluricolumnals, partial and complete calyces, and arm fragments over 3 m^2 on a very gently sloping surface. Five complete and 7 partial calyces and numerous stem segments were recovered in situ by excavation to 20cm beneath the lag gravel in the weathered zone.

The arms are delicate, quite slender and, based on a partial set of arms lacking all parts of the calyx, extended a minimum of 25cm above the tegmen. Although uniserial proximally, they become biserial in the middle and distal parts of the arm.

Neocamptocrinus sp. nov.
(Fig. 5A-C)

MATERIAL. QMF38900, part of exterior side of 2 rays of partial set of arms, QMF39006, part of interior side of 3 rays of partial set of arms, and QMF39007, pluricolumnal, from QML518.

DESCRIPTION. Axillary primibrach triangular, lateral ends nearly overlap 1st primibrach. Second secundibrach axillary. Brachials strongly convex transversely, straight longitudinally, very deep, cuneate, becoming biserial on the 8th tertibrach, rectilinear biserial on 11th tertibrach. Fine granular ornament on primibrachs and secundibrachs, smooth thereafter. Ambulacral groove narrow, deep V-shaped. Arms 20, 4 per ray, slender, very elongate, 65.8mm (incomplete). Pinnules slender, narrow, one per brachial.

REMARKS. Preservation of both specimens is moderately good, with some parts poorly preserved through oxidation by weathering. The arm branching is typical of *Dichocrinus* or *Neocamptocrinus* with 4 arms per ray. Arms are very delicate and larger than most dichocrinids. They are assigned to *Neocamptocrinus* based on the shape of the brachials, uniserial to biserial arm development, arm branching pattern, and pluricolumnals and columnals of *Neocamptocrinus* in the same interval of the Condamine Beds.

Neocamptocrinus? sp.
(Fig. 5D)

MATERIAL. QMF38880 from QML1237.

REMARKS. The partial set of arms is 20.1mm long, 9.4mm wide, and consists of parts of 14 arms. They are assigned to *Neocamptocrinus* because they closely resemble the arms of *N. millyitensis*, as the cuneate brachials are small, biserial, strongly rounded transversely, and bear small delicate pinnules. Webster (1987) reported pluricolumnals of *Camptocrinus* cf. *indoaustralicus* from the type section of the Callythara Formation. Although no cup or calyx has been recovered from the Callytharra Formation, these columnals are now considered to belong to *Neocamptocrinus*, because they are similar to those reported from several stratigraphic units in WA.

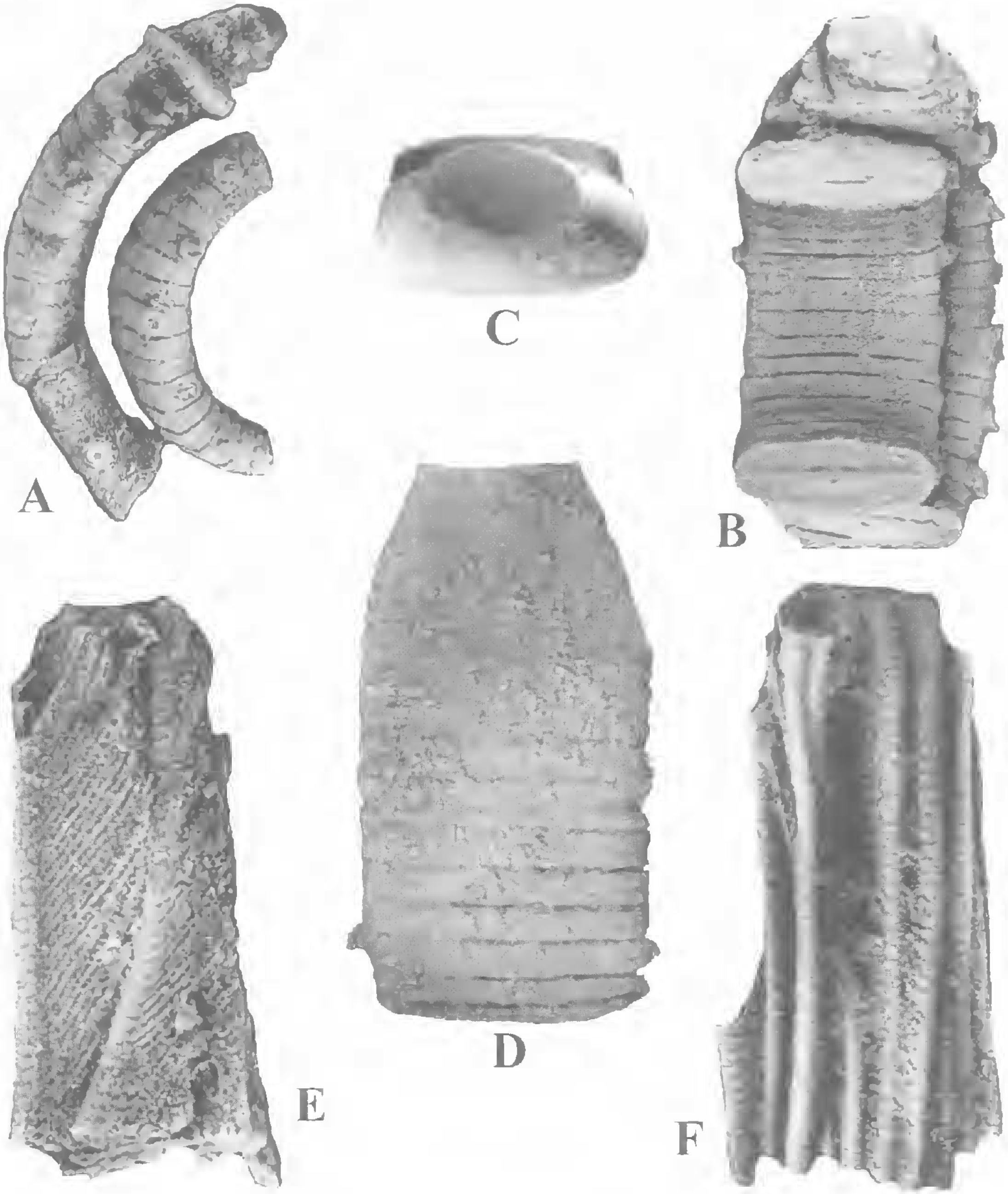


FIG. 4. *Neocamptocrinus millyitensis* Webster & Jell, 1992. A,B, lateral and inner views of coiled pluricolumnal QMF38028, ×2.5. C,D, proximal facet and outer views of expanding part of proximal pluricolumnal QMF38030, ×6.9. E,F, lateral views of partial set of arms QMF38025, ×3.3.

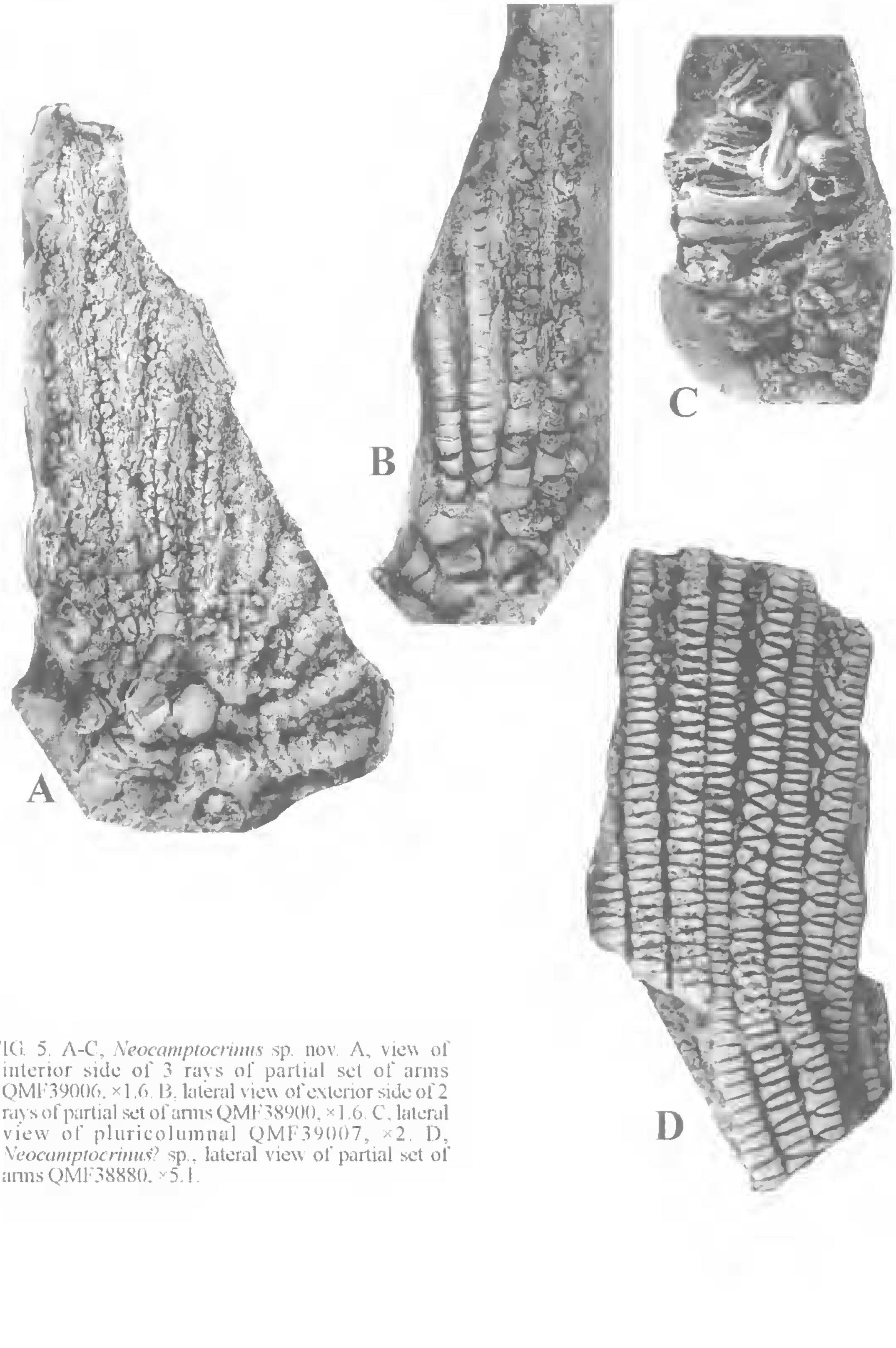


FIG. 5. A-C, *Neocamptocrinus* sp. nov. A, view of interior side of 3 rays of partial set of arms QMF39006, ×1.6. B, lateral view of exterior side of 2 rays of partial set of arms QMF38900, ×1.6. C, lateral view of pluricolumnal QMF39007, ×2. D, *Neocamptocrinus*? sp., lateral view of partial set of arms QMF38880, ×5.1.

Superfamily PLATYCRINITOIDEA
Austin & Austin, 1842
Family PLATYCRINITIDAE
Austin & Austin, 1842

Platycrinites Miller, 1821

TYPE SPECIES. *Platycrinites laevis* Miller, 1821 from the early Carboniferous of England, by subsequent designation of Meek & Worthen, 1865.

Platycrinites halos sp. nov.
(Fig. 6C,D)

ETYMOLOGY. Greek *halos*, a circle around the sun: refers to the elevated platform around the radial facet.

MATERIAL. Holotype, internal mould with part of proximal tegmen and external mould of basal circlet, 2 radials, and 1 interambulacral, QMF39008 from QML518.

DIAGNOSIS. Cup very large, bowl-shaped; radial facets concave, elliptical, subvertical; arms projecting horizontally away from cup; radial facets large, elliptical, on slightly projecting platforms.

DESCRIPTION. Cup large bowl-shaped, c. 25mm long, estimated 51mm wide, granular texture. Basal circlet large, 14,5mm long, 25mm wide. Basals 3, azygous half size 2 zygous, down widely flaring proximally beneath stem facet, upward widely flaring distally, forming proximal part of cup wall. Radials 5, large, 27mm long, estimated 27mm wide, moderately convex longitudinally, strongly convex transversely, distally shoulders incurved partly around angustary radial facet. Radial facet large, estimated 12.5mm long and wide, concave, elliptical outline, surrounded by narrow platform with sloping rim. Tegmen arched, unknown length. First interambulacral plates very large, estimated 12mm long, 15.7mm wide, laterally flanked by series of small plates covering ambulacral trackways. Stem facet large, estimated 14 ×10mm, separated from cup wall by narrow groove.

REMARKS. This is one of the very large calyx type *Platycrinites*. The arms proximally project horizontally away from the cup. The basal circlet forms a small part of the cup walls as it flares outward much more than upward. The radials are the main part of the cup wall, subvertical proximally and incurved distally. A disarticulated associated columnal beside the base of the cup is 3.2mm long and 18.6mm by an estimated 8mm in transverse section; latus moderately concave; fulcral ridge elevated well above adjacent pits. It is one of the straight columnals of the segmented twist type of Webster (1997) and probably from the same specimen as the cup. The size of the radials is close to that of *Platycrinites* sp. of Webster & Lane (1967) from the Artinskian part of the Bird Spring Formation of southern Nevada. However, no other species of *Platycrinites* has the elevated or rimmed radial facets like *P. halos*.

Platycrinitid indet. (columnals)
(Fig. 6A,B)

MATERIAL. QMF38899, 39009, 39010 from QML518.

REMARKS. Elliptical columnals belonging to a platycrinitid, such as *Platycrinites*, *Neoplatycrinus*, or *Stomiocrinus* are of the segmented twist type (Webster, 1997). The facets bear a dual transverse ridge divided by a shallow groove along the long axis. They have an axial canal and 2 or 3 coarse crenulae and culmina on the distal ends of the long axis. Straight and twist columnals are present. They are mentioned to show crinoid diversity in the Condamine Beds.

Subclass CLADIDA Moore & Laudon, 1943
Superfamily CYATHOCRINITOIDEA
Bassler, 1938
Family EUSPIROCRINIDAE Bather, 1890

Anaglyptocrinus gen. nov.

TYPE SPECIES. *Anaglyptocrinus willinki*, late Artinskian Wandrawandian Siltstone at Warden Head, NSW.

ETYMOLOGY. Greek *anaglyptos*, wrought in relief, and *krinon*, lily; refers to the low relief, weathered out condition of the holotype.

DIAGNOSIS. Cup medium bowl, with nodose ornament, with shallow apical impressions; infrabasal circlet flat to gently upflared; radial facet angustary, wide radial notches; single large anal above posterior basal; brachials rectilinear, strongly convex transversely, with 4 rows of cover plates above V-shaped ambulacral groove; arms branching isotomously on 4th primibrach and once or twice more; brachials with very small internal axial canal, brachial facets trifacial; anal tube narrow, elongate; stem round, with round lumen.

REMARKS. *Anaglyptocrinus* is distinguished from all other euspirocrinids by the flat to very low basal circlet, medium bowl-shaped cup, and the single anal plate. Cup shape is most similar to but shorter than *Euspirocrinus*. Other taxa assigned to *Anaglyptocrinus* are *Gissocrinus*? *voiseyi* Willink, 1979 and *Gissocrinus*? sp. Willink, 1979.

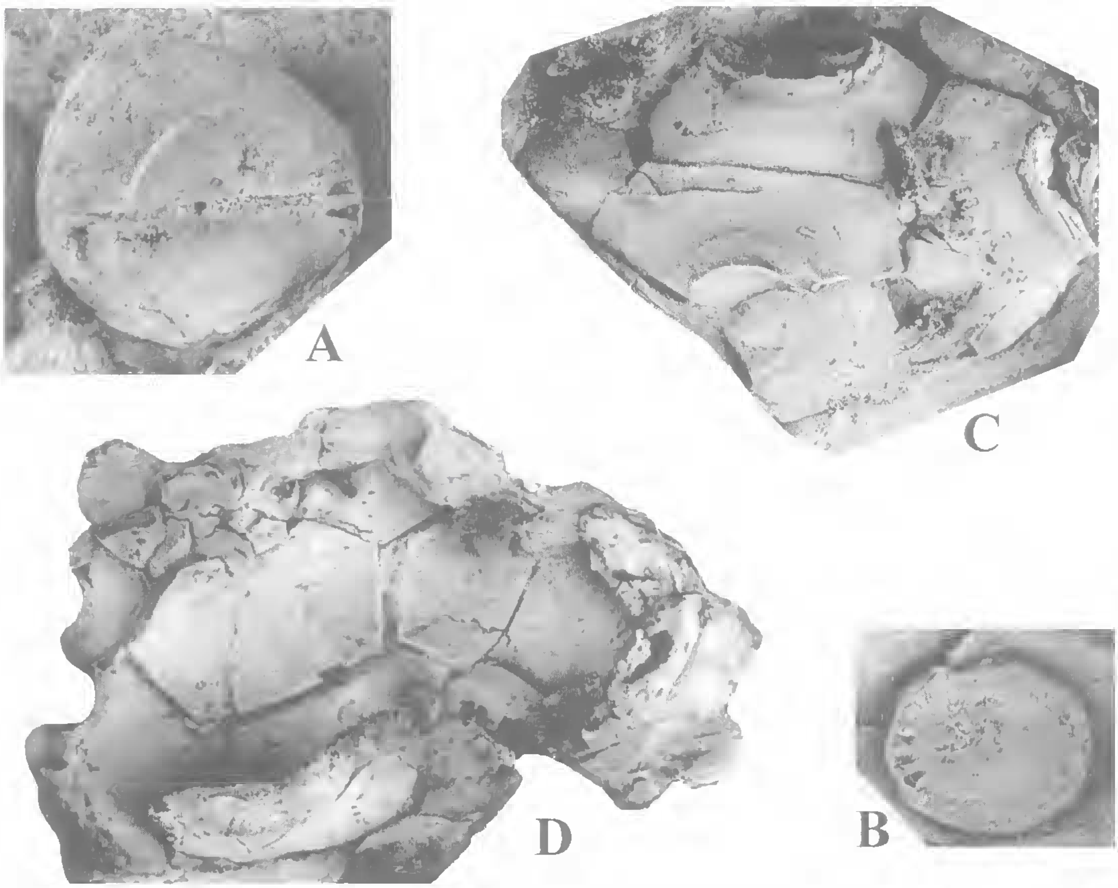


FIG. 6. A,B, Platycrinitid indet. columnals. A, facetal view of twist columnal QMF38899, ×3.6. B, facetal view of weathered straight columnal QMF39009, ×3.8. C,D, *Platycrinites halos* sp. nov., external (×1.5) and internal (×1.3) views of slightly disarticulated and distorted partial theca, holotype QMF39008.

Anaglyptocrinus willinki sp. nov.
(Fig. 7)

ETYMOLOGY. For R. Willink in recognition of his studies of the Permian crinoids of eastern Australia.

MATERIAL. HOLOTYPE: QMF38913 from QML859.

DIAGNOSIS. As for genus, cup ornament nodose.

DESCRIPTION. Crown slender, elongate, 20.8mm preserved. Cup medium bowl-shaped, nodose ornament on all cup plates, double row of nodes on proximal edge of radial parallel to basal-radial sutures, shallow impressions at junction of basals and radials. Infrabasal circlet flat to widely flaring, barely visible in lateral view. Basals 5, large, 4mm long (incomplete), 5.6mm wide, moderately convex longitudinally and transversely, incurved proximally, subvertical distally, forming lower half of cup wall. Radials 5, 4.4mm long, 5.7mm wide, straight longitudinally below facet, convex longitudinally adjacent to facet, moderately convex transversely. Radial facet narrow, strongly convex outer edge, flaring inwardly to merge with radial shoulders, inner edge smooth with wide concave ambulacral notch, declivate; transverse ridge prominent, divided by gap in middle, dividing facet into inner and outer halves; outer half with small 4-lobed elevation off centre, slightly aboral to gap in transverse ridge; outer fossa divided by low rise from 4-lobed elevation into 2 shallow transversely elongate parts, deepest central aboral; inner fossa transversely elongate, shallow. Radial notches wide. Single anal large, pentagonal, projecting slightly above radial summit, proximally abutting terminated end of CD basal, distally adjoining 2 proximal tube plates. Arms slender, branching isotomously on 4th primibrach and 4th or 5th secundibrach; more distal branching

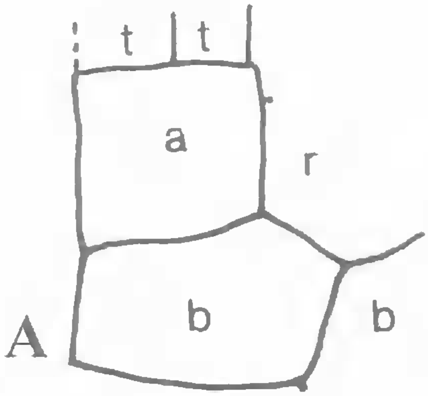


FIG. 7. *Anaglyptocrinus willinki* gen. et sp. nov. A, camera lucida sketch of posterior (×6). B, A ray (×2.8) view. QMF 38913. t = tegmen plates, a = anal X, r = C ray radial and b = CD (left) and BC (right) basals.

unknown. Brachials straight longitudinally, strongly convex transversely, deep, with wide V-shaped ambulacral groove. Brachial facets trifacial; transverse ridge wide V, apex pointed adoral, with small single axial canal in slightly elevated centre. Ambulacral cover plates small, 0.05mm long and wide, polygonal, interlocking with adjacent plates longitudinally and laterally; 4 across ambulacral groove, merging with small polygonal plates of tegmen proximally. Anal tube slender, elongate, of 10-11 vertical rows of smooth, laterally interlocking hexagonal plates, 2mm wide, 1.8mm long. Column heteromorphic; noditaxis pattern N3231323. Columnals, round transversely; latus moderately to strongly convex on nodals and internodals; nodals cirrate throughout 21mm of preserved column. Axial canal round.

REMARKS. The crown is crushed with distal parts of the arms and tegmen lost to weathering and the infrabasals and anals are not exposed. Excavation of the under side exposed the C radial, BC and CD basals, parts of the infrabasal circlet, primanal and proximal parts of 2 tube plates (Fig.7A). Ornamentation of the cup was lost or very faintly preserved on parts of the exposed cup, but well-developed on the excavated cup plates.

Willink (1979a) described *A. voiseyi* and *A.* sp. from the Cataract River Formation and Catherine Sandstone, respectively. These forms show similarity of the cup shape and arm branching pattern to the Wandrawandian specimen. They differ from the nodose ornamented cup of *A. willinki* by *A. voiseyi* being ornamented with nodes and sharp ridges on all cup plates as well as the brachials and *A.* sp. bearing prominent interconnected plate ridges on the cup and proximal and distal expanded rims on the brachials giving them an hourglass shape. Thus, the 3 forms make a series from simple nodose ornament to highly ornate, with the simple nodose form the oldest (late Artinskian) and the 2 younger more ornamented forms of approximately the same age (Roadian). Ray ridge and interconnected ray ornament in the crinoids is common in the actinocrinitids, primitive poteriocrinitoids, and a few flexibles. It is not as common in the late Palaeozoic as in the early and middle Palaeozoic. Thus, the ray ridge ornament of the younger forms is considered heterochronous homeomorphy.

Willink (1979a) considered *Glyssocrinus* in need of revision, noting that the diagnosis provided by Moore & Teichert (1978) was narrower than that of Angelin (1878) or Bather (1893). Furthermore, he suggested that the Australian forms probably represented the end members of a conservative stock of the cyathocrinitids that was most closely allied to the Silurian *Gissocrinus*. However, he also suggested the possibility, that the Australian specimens represented heterochronous homeomorphy. The first branching of the arms of *Gissocrinus* is on the single primibrach and the cup is a low bowl, both advanced evolutionary features for this Silurian taxon. By comparison, the type species of *Cyathocrinites*, an Early Carboniferous taxon, has a medium bowl cup and the first branching of the arms is on the 3rd primibrach, both more primitive features. *A. willinki* has even more primitive arm branching than *Cyathocrinites*, but a slightly more advanced cup form. The primitive arm branching with ambulacral cover plates suggests evolution from an unknown conservative stock of the cyathocrininids. The trifacial articulation facets of the brachials and internal dual axial canals are advanced features found in some of the stem articulate crinoids (Simms & Sevastopulo, 1993).

Necopinocrinus gen. nov.

TYPE SPECIES. *Necopinocrinus tycherus* sp. nov. from the Condamine Beds, Elbow Valley area, near Warwick, SE Queensland.

ETYMOLOGY. Latin *necopinus*, unexpected, and *crinon*, lily; refers to a euspirocrinid not being expected to occur in the Permian.

DIAGNOSIS. Cup expanded low bowl, with constricted base, with incurved radial, with coarse nodose ornament on all cup plates; 3 infrabasals, small infrabasal in C ray; radial facets angustary, 1/3 radial width, horseshoe-shaped; 3 small anals above posterior basal; single primibrach axillary. Arms widely spread, branching isotomously. Brachials cuneate; stem round transversely.

REMARKS. The expanded low bowl-shaped cup and axillary 1st primibrach are the 2 most distinctive charaters of *Necopinocrinus*. The cup is most similar to, but more bowl-shaped, than the low cone-shaped cup of *Vasocrinus*.

Necopinocrinus tycherus sp. nov.
(Fig. 8)

ETYMOLOGY. Greek *tyche*, luck or chance, and refers to the Lucky Valley Creek wherein the specimen was found.

MATERIAL. HOLOTYPE: QMF38901, from QML518.

DIAGNOSIS. As for genus.

DESCRIPTION. Cup expanded, low bowl, with constricted flat base, 15mm long, 39mm wide (crushed, compacted in part); all cup plates with coarse nodes, some grading into very short ridges. Infrabasal circlet large, with large circular stem facet, constricted subvertical above stem facet, expanding upflaring distally, divided into 3 plates, 2 large equal plates and 1 smaller plate in C ray, visible in lateral view. Basals large, upflaring, gently convex longitudinally and transversely, forming major part of cup; D-E basal 12mm long (estimated), 20mm wide. Posterior basal 14.8mm long, 10.4mm wide, truncated distally by 3 small facets for anals. Radials large, 12mm long, 18.4mm wide, strongly convex longitudinally, moderately convex transversely, strongly incurved distally to near subhorizontal. Radial facet angustary, horseshoe-shaped, 7.4mm wide, deep, subhorizontal. Three anals small, in line of radials, probably projected slightly above radial facet. Anal tube not preserved. Single primibrach axillary, 5.2mm long, 5.2mm wide, straight longitudinally, strongly convex transversely; distal facets wide spread, separated by narrow concave trough. Secundibrachs wider than long, weakly cuneate, straight longitudinally, strongly convex transversely. Primibrachs and proximal 2 secundibrachs with coarse nodes, with line of coarser nodes along lateral edges. Stem large, circular in transverse section, 9mm diameter.

REMARKS. The crown of *Necopinocrinus tycherus* is crushed along the A-CD plane of symmetry. Radials are cracked and impacted downward, overlapping the distal tips of the basals, the E-A basal is inset and edges are overlapped by adjacent plates, the infrabasal circlet is compressed, brachials are slightly offset from the cup and one another, and the stem and distal parts of the crown are lost.

This specimen represents a conservative stock of the Euspirocrinidae showing an advanced condition of: 1, the anals restricted to the area above the extended posterior basal; 2, the infrabasal circlet of 3 plates; and 3, the arms branching on the single primibrach. *Anaglyptocrinus* and *Neeopinocrinus* are the first post Carboniferous euspirocrinids reported, extending the range of the family into the Late Permian.

Superfamily SCYTALOCRINOIDEA
Moore & Laudon, 1943
Family SPANIOCRINIDAE
Moore & Laudon, 1943

Spaniocrinus Wanner, 1924

TYPE SPECIES. *Spaniocrinus validus* Wanner, 1924 from the Permian Basleo Beds of Timor; by original designation

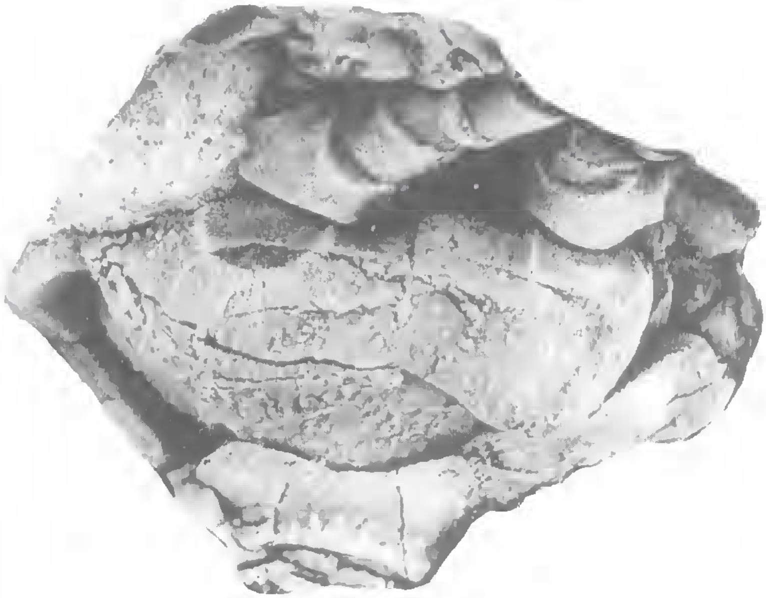


FIG. 8. *Necopinocrinus tycherus* gen. et sp. nov., D-E interray view of partial crown QMF38901, ×1.7.

Spaniocrinus geniculatus sp. nov. (Fig. 9)

ETYMOLOGY. Latin *geniculatus*, like the bent knee; refers to the knee-shaped brachials.

MATERIAL. HOLOTYPE: QMF38987 from QML518. PARATYPE: QMF39011, same.

DIAGNOSIS. Crown slender, elongate; cup medium bowl; ornament of coarse nodose to short irregular ridges continuing onto brachials, with prominent longitudinal ridge or keel along middle of brachials; brachials rectilinear to slightly cuneate, interlocking laterally. Arms 5. Stem round, heteromorphic.

DESCRIPTION. Crown slender, elongate, 57.3mm long (incomplete), 21.2mm wide, widest at first brachial, tapering distally. Cup medium bowl, 6mm long, 18mm wide, with coarse nodose to irregular ridge ornament, continuing onto brachials; sutures impressed. Infrabasal circlet small, not exposed, may be in shallow impression. Basals 5, convex longitudinally and transversely, proximally forming base of cup, distal part forming base of cup walls, widely outflaring. Radials 5, large, wider (9.5mm) than long (6mm), strongly convex longitudinally, moderately convex transversely, tumid, outflared. Radial facet plenary. Brachials much wider than long (first brachial 4.5mm long, 10.5mm wide), rectilinear to slightly cuneate, moderately convex transversely, straight longitudinally, prominant central longitudinal ridge or keel, with coarse nodose ornament, interlocking laterally, transverse ridges and grooves on lateral ends exterior to pinnular facets; 2 small pinnules on each side, transverse outline angular. Arms 5, tapering distally. Anals not exposed. Stem round, 5mm diameter, heteromorphic; noditaxis pattern N212, cirriferous on second nodal below cup; 53.6mm preserved. Columnals moderately long, (nodals 3.5mm long, internodals 2.6mm long 31mm below cup); latus convex, with coarse nodose ornament proximal to cup, smooth distally. Cirri round, 2.5mm diameter.

REMARKS. The external mould of the crown and proximal stem of the holotype has the distal part of the arms partly disarticulated and central parts of the arms missing. Parts of 4 rays are preserved. The paratype is a set of arms, lacking the cup. The medial ridge on the brachials is well developed on both the holotype and paratype. Measurements taken from latex cast of holotype.

Comparisons are made with species of *Spaniocrinus* and *Parspaniocrinus* because the two genera are closely related. The medium bowl-shaped cup of *S. geniculatus* is lower than that of either *S. validus* Wanner, 1924, *S. transcaucasicus* Yakovlev, 1933 or *Parspaniocrinus beinerti* Strimple, 1971, all of which have truncated medium cones, and *S. trinodus* Weller, 1909 has a much narrower turbinate cup. The coarse nodose ornament of *S. validus* and *S. transcaucasicus*, the triple nodes on the radials of *S. trinodus*, and the fine granular ornament of *P. beinerti*, lack the irregular longitudinal ridges of *S. geniculatus*. Brachials of *P. beinerti* have a rounded exterior in transverse section, whereas brachials of *S. geniculatus* are like the angular transverse outline of *S. validus*. The cup and shorter brachials of *S. geniculatus* are advanced features, probably derived from *S. validus*.

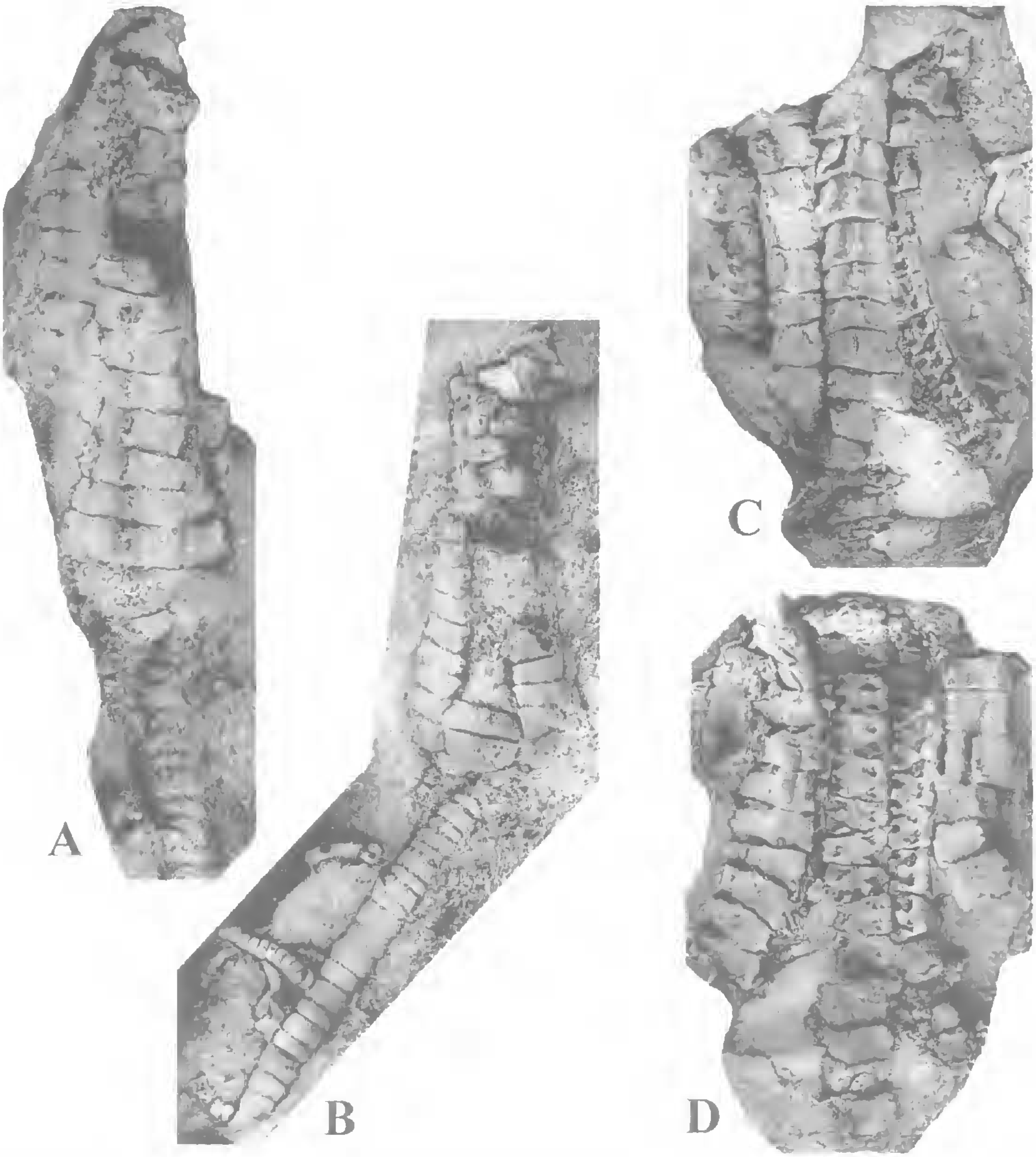


Fig. 9. *Spaniocrinus geniculatus* sp. nov. A,B, enlarged (×1.7) view of ray to left in figure B and lateral view of crown (×1.1), holotype QMF38987. C,D, exterior and interior views of partial set of arms, paratype QMF39011. ×1.8.

Superfamily DECADOCRINOIDEA Bather, 1890
Family DECADOCRINIDAE Bather, 1890

DIAGNOSIS. Moore & Strimple (in Moore & Teichert, 1978: 685) gave the diagnosis as: 'Crown slender. Cup widely expanded, truncate cone or bowl shaped with small basal concavity; five infrabasals with only distal tips at most visible in side view; five medium-sized basals; five radials with articular facets as wide as plates; one to three anals in cup; anal sac tall, slender. Arms ten, formed of cuneate uniserial brachials.

branching isotomously on primibrachs 2 in geologically older forms, and on primibrachs 1 in later ones, no further branching, arms sinuous or zigzag in appearance, pinnules stout, tending to resemble ramules. Stem preponderantly round transversely and noncirriferous (except *Aulocrinus*).'

REMARKS. The Decadocrinidae were recognised primarily on the zigzag nature of the 10 arms and Moore & Strimple (in Moore & Teichert, 1978) considered them intermediate in evolutionary development between some of the genera with rectilinear uniserial arms and some with biserial arms. Taxa with more than 10 zigzag arms were assigned to one of several families based on arm branching patterns and other cup features (i.e. *Plummericrinus* in the Pachylocrinidae; *Sphenjscocrinus* in the Ampelocrinidae). Using the zigzag nature of the 10 arms, *Holcocrinus* should have been assigned to the Decadocrinidae instead of the Graphiocrinidae. Without the zigzag appearance of the arms, genera assigned to the Decadocrinidae could have been assigned to the Scytalocrinidae or Graphiocrinidae on the basis of cup shape and number of anals within the cup. However, except for *Parascytalocrinus* all scytalocrinids have a truncated cone-shaped cup. *Parascytalocrinus* was established by Kammer & Ausich (1993) for species with a low bowl-shaped cup with a flat or shallow basal invagination and an atomous A ray previously assigned to *Scytalocrinus*. In the same paper, they erected *Lanecrinus* for species with 10 zigzag arms previously assigned to *Scytalocrinus*. This restricted *Scytalocrinus* to species with conical cups and non zigzag arms.

If the zigzag pattern of the brachials is looked at closely, most genera show that it is dominantly the result of a slight to moderate extension on the long side of the cuneate brachial into a distal shoulder where the pinnule attaches. A node or blunt spine, which accentuates the zigzag appearance when present, may be positioned on the distal shoulder adjacent to the pinnule facet on the outer side of the brachial. *Trautscholdicrinus* lacks the zigzag appearance of the arms, but shows a faint zigzag pattern on the medial keel of the cuneate brachials.

There is considerable difference in the length of the brachials in the Decadocrinidae. The brachials of *Trautscholdicrinus*, *Zostocrinus* and *Eireocrinus* are the longest, *Glaukosocrinus* has intermediate length brachials and all other genera have very short brachials. With the exception of

FIG. 10. *Glaukosocrinus middalyaensis* sp. nov., posterior view of holotype QMF38881, ×2.2.

Decadocrinus and *Zostocrinus* they branch on the single primibrachials.

The genera of the Decadocrinidae do not fit into an evolutionary lineage and the family is herein considered polyphyletic. They probably represent advanced taxa evolved from several conservative genera within the cuneate brachial clade recognised by Webster (1997) or other rectilinear brachial genera. Revision of the Decadocrinidae is beyond the scope of this study and should be incorporated in a revision of the Poteriocrinina. Until such a study is completed the Decadocrinidae is retained for convenience.

Glaukosocrinus Strimple, 1951

TYPE SPECIES. *Malaiocrinus parviusculus* Moore & Plummer, 1940 from the Desmoinesian Millsap Lake Formation, Parker County, Texas; by original designation.

Glaukosocrinus middalyaensis sp. nov.
(Fig.10)

ETMOLOGY. From Middalya Station, WA.

MATERIAL. QMF38881 from QML1240.

DIAGNOSIS. Crown cylindrical, with very fine nodose to vermiform ornamentation; cup with basal invagination; radial facets peneplenary; 3 anals in cup; radianal and anal X large; single axillary primibrach elongate; brachials cuneate; large pinnules relatively short; 10? arms distinctly zigzag; stem round, with narrow crenularium, with wide areola, with round small lumen.

DESCRIPTION. Crown cylindrical, medium size, incomplete length 43.1mm, crushed width 26.4mm, very fine nodose to vermiform ornamentation extending onto arms. Cup medium bowl, shallow basal invagination, crushed length 10mm, crushed width 20mm maximum, 8.2mm minimum. Infrabasals 5, small, horizontal, in basal invagination, not visible in lateral view. Basals 5, medium size, strongly convex longitudinally, moderately convex transversely, forming walls of basal invagination, basal plane, and base of cup walls. Radials 5, large, length 8.2mm, width 9.1mm, gently convex longitudinally and transversely. Radial facet peneplenary, deep, sloping outward strongly. Anals 3; radianal large, 8mm long, 6mm wide, adjoining C radial, CD and DE basals, anal X, and right tube plate; anal X pentagonal, large, 7.8mm long, 6mm wide, widest near distal end. Right tube plate elongate, 5.6mm long, 4.1mm wide, narrowest on proximal end, proximal 1/3 below radial summit. Single primibrach axillary, constricted medially, length 8.1mm, width 7.7mm, widest on proximal end, strongly convex transversely, concave longitudinally. Brachials cuneate, approximately equidimensional, strongly convex transversely, straight longitudinally, with wide pinnule facet on alternating distal ends giving arms distinct zigzag appearance. Pinnules wide, stout, relatively short. Ambulacral groove deep V-shaped. Arms 10? Stem round; facet with narrow crenularium, wide areola, narrow round lumen.

REMARKS. The crown is crushed and cup plates are dislocated in part. The infrabasal circlet was partly exposed by cleaning and barely extends beyond the stem facet. Only 3 basals are preserved and all are distorted by compaction. Solution weathering has destroyed most surface ornament except along part of the D radial, anal X and first tube plate.

Glaukosocrinus middalyaensis is distinguished from *G. parviusculus* (Moore & Plummer, 1940) and *G. planus* Strimple & Moore, 1971 by the very fine anastomosing ornament. In addition, the primibrach is longer than that of *G. planus*.

This is the first report of *Glaukosocrinus* outside North America and the first in the Permian. The peneplenary radial facets make relatively narrow radial notches as on the cup of *G. parviusculus*. The arm branching on the single primibrach and shallow basal invagination are advanced features, while the 3 anals in the cup is a primitive feature. These features did not change significantly in the Late Carboniferous or Early Permian.

Eidosocrinus gen. nov.

TYPE SPECIES. *Eidosocrinus condaminensis* sp. nov. from the Condamine Beds, Elbow Valley area, near Warwick, SE Queensland.

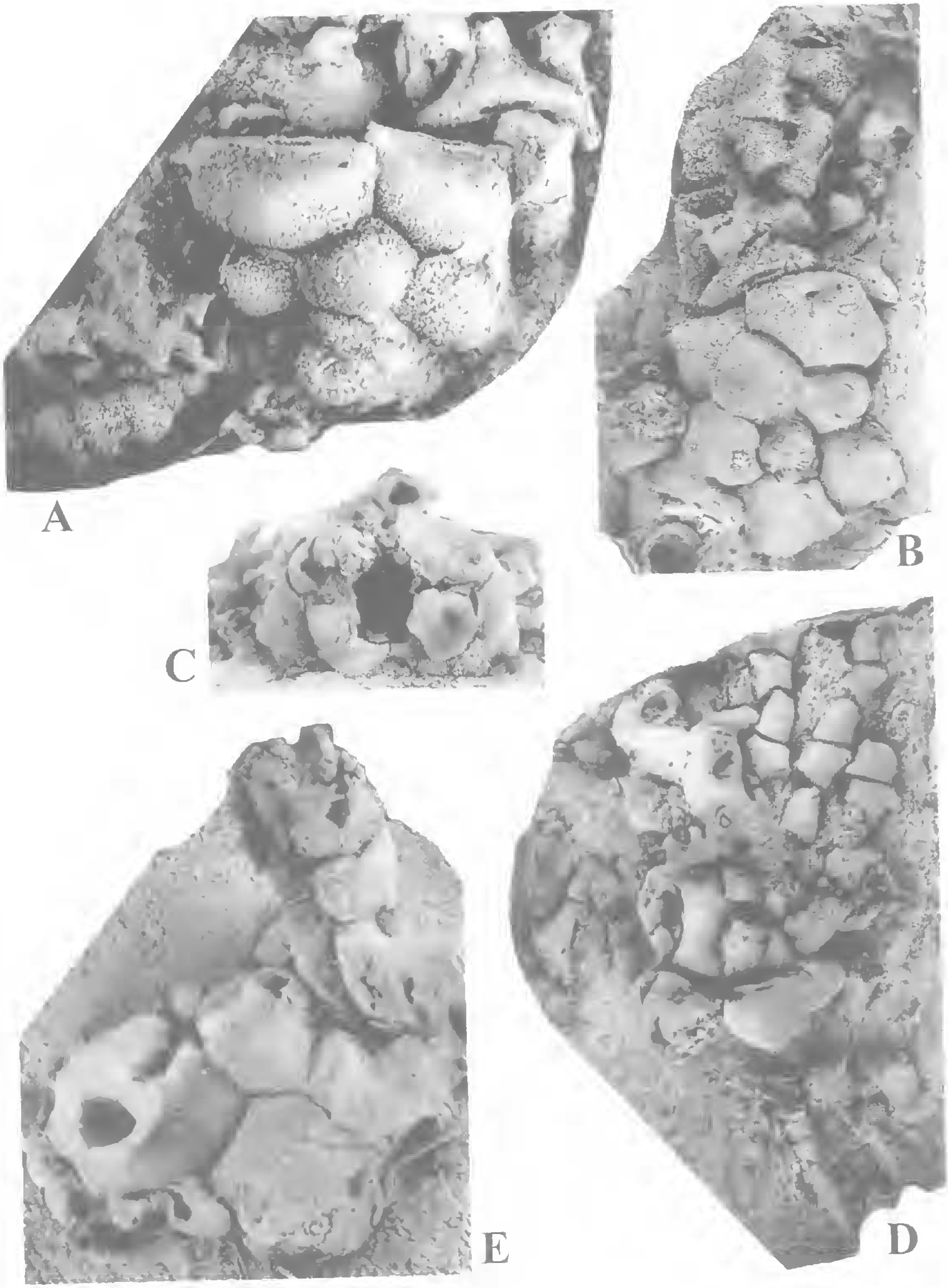
ETYMOLOGY. Greek *eidos*, form or likeness, and *krinon*, lily; refers to the types based on latex casts.

DIAGNOSIS. Crown cylindrical; cup low bowl-shaped, base invaginated, one anal, with single axillary primibrachs of differing lengths in different arms, cuneate brachials, 10 arms zigzag, coarse horn like nodes or blunt spines on the basals, radials, and distal tips of all brachials, fine granulate ornament on basals and radials.

REMARKS. Mild to moderate tumidity of cup and arm plates in the Poteriocrinina is known in *Spheniscocrinus* and *Cromyocrinus*, among others. Likewise, coarse nodes or blunt spines on the axillary brachials are developed on the Pirasocrinidae (*Pirasocrinus*, *Sciadocrinus*) and Zeacrinitidae (*Tholocrinus*), among others. *Triceracrinus* (assigned to the Pirasocrinidae) has coarse horn-like nodes on the basals, radials and primibrachs (similar to those of *Eidosocrinus*), but lacks the nodes on the very short, weakly cuneate secundibrachs that have a medial transverse ridge. Thus, the ornamentation of *Eidosocrinus* is a distinguishing character.

The differing length from ray to ray of the

FIG. 11. *Eidosocrinus condaminensis* sp. nov. A, lateral view of disarticulated partial crown, paratype QMF38904, ×2.6. B, basal view of slightly disarticulated crown, paratype QMF38903, ×2.7. C,D, basal (×2.2) and B ray (x1.8) views of holotype QMF38902. E, internal view of posterior interray, paratype QMF38905, ×4.3.


A
B
C
D
E

axillary primibrachs of *Eidosocrinus* is found in several Scytalocrinidae, Aphelecrinidae, Graphiocrinidae, among other poteriocrininids. This feature is considered intermediate between branching above the first primibrach and on the single primibrach. Combined with features of the cup it may reflect a closer evolutionary relationship of the Scytalocrinidae, Aphelecrinidae and Decadocrinidae than with the rectilinear brachials of the Stachyocrinidae.

Eidosocrinus condaminensis sp. nov.
(Fig. 11)

ETYMOLOGY. From the Condamine Beds.

MATERIAL. HOLOTYPE: QMF38902 from QML518. PARATYPES: QMF38903-38905, same.

DIAGNOSIS. As for genus.

DESCRIPTION. Crown incomplete, 34.1mm preserved, cylindrical, ornament of single coarse horn-like node or blunt spine on all basal, radial, and brachial plates. Cup low bowl-shaped, 17.8mm wide, 8.8mm long, base invaginated, fine granular ornament. Infrabasal circlet small, 5.1mm diameter, subhorizontal, not visible in lateral view. Basals 5, 4.5mm long, 5.3mm wide, strongly tumid, outflared, forming base of cup and walls. Radials large, 5mm long, 7.5mm wide, strongly tumid, slightly flaring, forming most of cup wall. Radial facet plenary, subhorizontal, slightly concave transversely, deep, with elevated transverse ridge on central 1/3, deep elongate ligament pit, wide outer margin. Primanal large, 4mm long, 4.7mm wide, very tumid, abutting distally terminated posterior basal, proximal 1/2 in line of radials, distal 1/2 projecting above radial summit, distally adjoined by 2 anal tube plates. Single primibrachs axillary in all rays, A ray longest (8.5mm), C ray intermediate (greater than 4.7mm), B and E rays shortest (4.9mm), strongly convex transversely, concavo-convex longitudinally, hourglass-shape in exterior view. Secundibrachs cuneate, approximately as wide as long, deep, strongly convex transversely, straight proximally becoming convex distally, node adjacent to pinnule facet on long side. Branching isotomously, 10 arms. Stem round, heteromorphic; noditaxis pattern N1. Columnals moderately long; crenularium narrow; lumen small, circular?; latus roundly convex on nodals, gently convex on internodals.

REMARKS. Description of *Eidosocrinus condaminensis* is based on the casts of all types because no specimen is complete. Measurements made on

FIG. 12. A,B, *Eoindocrinus praecontignatus* Arendt, 1981, oblique lateral and lateral views of cup QMF38910, ×5.2. C, *Pedinocrinus? nodosus* sp. nov., C-D interray view of holotype QMF38906, with *E. praecontignatus* cup on arms in upper right, ×1.7.

the holotype. The holotype has part of the D, A, B, and C rays; some cup and arm plates are dislocated slightly. The infrabasal circlet, D-E basal plate, E ray, and anal are lost through weathering. A poorly preserved pluricolumnal in alignment with, directly below, and 6mm from the cup is probably part of the stem. It is round, 2.2mm diameter, heteromorphic (noditaxis pattern N1) with moderately elongate columnals. Paratype QMF38903 is crushed, all cup plates are slightly dislocated, the proximal columnal nearly covers the infrabasal circlet, and only the proximal part of the E and A rays are preserved. Paratype QMF38904 is also crushed and retains part of the cup, proximal columnals, and primibrach of one ray. Paratype QMF38905 is an internal and external mould of a cup showing the basals, radials, anal, and C ray primibrach. The fine granular ornament is preserved on some cup plates of all 4 specimens.

Tentative assignment of *Eidosocrinus condaminensis* to the Decadocrinidae is for convenience and based primarily on the zigzag nature of the arms.

Superfamily LOPHOCRINOIDEA Bather, 1899

Family STELLAROCRINIDAE Strimple, 1961

Pedinocrinus Wright, 1951

TYPE SPECIES. *Pachylocrinus clavatus* Wright, 1937 from the Early Carboniferous, Tournaisian, Lower Limestone Group, Scotland; by original designation.

Pedinocrinus? **nodosus** sp. nov. (Fig. 12C)

ETYMOLOGY. Latin *nodus*, nodes; refers to the nodose ornament of the cup and proximal brachials.

MATERIAL. HOLOTYPE: QMF38906, from QML518.

DIAGNOSIS. Crown flaring distally, cup low bowl-shaped, 3 anals, coarse nodose ornament continuing onto proximal brachials, 1st primibrach, 8th secundibrach and 9th tertibrach axillary; bulbous tegmen; stem round, heteromorphic.

DESCRIPTION. Crown moderately large, 47.7mm long (incomplete), 42.3mm wide (still expanding), pear-shaped, arms flaring. Cup low bowl, 20mm wide (incomplete?), 6.5mm long (estimate), base invaginated. Coarse nodose ornament on all cup plates, primibrachs and proximal 3-4 secundibrachs; all axillary brachials above primibrachs nodose or bearing short blunt spines. Infrabasal circlet not exposed, within impressed basal cavity. Basals relatively small, 4mm long, 4.8mm wide, tumid, moderately convex longitudinally and transversely, subhorizontal to gently upflared. Radials largest cup plates, 3.6mm long, 8.8mm wide, moderately convex transversely, strongly convex longitudinally. Radial facets plenary. Anals 3, moderately large; radianal in CD interray, supporting both rectangular anal X and right tube plate directly above in radial circlet. Brachials cuneate, uniserial to biserial, strongly convex longitudinally and transversely, sutures impressed, one pinnule on widest side. In C ray 1st primibrach, 8th secundibrachs, and 9th tertibrachs axillary, probably 1 or 2 additional branchings distally. All branching isotomous, minimum of 40 arms if all rays branch as in C ray. Arms flare moderately laterally. Anal tube large, probably bulbous, formed of many small polygonal plates. Stem round, heteromorphic; noditaxis of N212 or N1 in proximal 20mm preserved. Columnals with strongly convex latus.

REMARKS. The external mould of *Pedinocrinus*? *nodosus* preserves part of the posterior side of the cup, the proximal parts of the C and D rays including some quartibrachs and tegmen plates. Cup plates are partly dislocated with the C radial nearly covering the right tube plate. The cup is covered by a cladoporid coral in part. All measurements are approximate, from latex casts.

At first glance *P.*? *nodosus* appears to resemble *Plaxocrinus*, *Tholocrinus* and *Hydreionocrinus*, all of which have moderately large flaring crowns with a low bowl-shaped or discoidal cup, axillary brachials bearing short spines or blunt nodes and large inflated tegmens. However, these taxa are placed in different familes based on the number of anals in the cup, type of brachials, and arm branching patterns. These taxa range in age from Early Carboniferous into the Late Permian and represent heteromorphic evolution within different lineages of the poteriocrininids in the late Palaeozoic.

Lacking ornamentation this specimen would be placed in *Pedinocrinus* without question. Arguments could be made for erecting a new genus for *P.*? *nodosus*. However, we do not believe that ornament alone is sufficient for establishing a new genus. The significant time gap between the Tournaisian *P. clavatus* (Wright, 1937) and the Artinskian *P.*? *nodosus* suggests *Pedinocrinus* may be a holdover in Australia. The coarse nodose ornament on the cup plates and proximal brachials of *P.*? *nodosus* should assist future recognition.

Stellarocrinid? gen. et sp. nov. (Fig. 13C)

MATERIAL. UQF12211A, from QML518.

DESCRIPTION. Cup unknown. Arms broad, widespread. Brachials uniserial, 4.6mm long, 11.5mm wide, mildly cuneate, deep, with coarse nodose ornament; with very large blunt node elongated parallel to arm length on inner side of long end, with notch for pinnule facet on outer side of short end. Ambulacral groove large, 2mm wide, V-shaped, joined by side grooves from short end of brachials. C and D ray arms branching isotomously on single primibrach, may branch again distally. Branches widely flared laterally. Tegmen formed of several inflated small (3.6mm diameter) to medium sized (7mm diameter) polygonal plates adjacent to 2 inflated very large orals (11mm diameter) at base of large anal tube (19mm diameter). Base of anal tube formed of 5 columns of vertically stacked plicate hexagonal plates (5.6mm long, 6.4mm wide); anal tube length unknown. Additional columns of tegmen plates not preserved, estimated minimum of 4 or 5 present. Smaller (3.6mm long and wide) anal tube plates projecting outward from the 3rd row of tube plates.

REMARKS. The specimen is an external mould of the oral surface of a large partial crown consisting of parts of 7 arms probably belonging to 5 rays. The 2 arms of the C and D rays branch close to the tegmen and the ambulacral groove of each of the 2 adjacent arms (B and E rays) join the ambulacral groove of the C and D rays before passing into the interior of the tegmen. It could be proposed that each of these sets of 3 arms are part of 1 ray, which would require 2 more rays behind the tegmen and not preserved. This is not likely with the excellent preservation and spacing of the arms. The 7th arm, the A ray, is undivided on the preserved part. The distal end of the E ray is regenerated, as distal brachials are much smaller than proximal brachials. The first brachial of the regenerated section is axillary. All arms probably branch again distally. All measurements are approximate, taken from a latex cast.

Although pinnules are not preserved their presence is presumed because notches for their attachment are present on the outer side of the brachials and a large U-shaped ambulacral groove along the short end of the brachial adjoins the main ambulacral groove. Attachment of the pinnules to the short end of the brachials is an exception to the normal attachment on the long end. Both the development of the large nodes on the inside of the long end of the brachial and the pinnule attachment on the short end are considered evolutionary developments of the specimen, not known in other poteriocrininids.

The small anal tube plates projecting laterally from the anal tube probably represent the distal parts of a recurved anal tube. The plates are slightly disarticulated and adjoined more distal plates that are not preserved.

The specimen represents a new genus but is considered inadequate to serve as a holotype, lacking the cup. It is assigned to the stellarocrinids because the laterally projecting arms spread widely, structure of the large elongate anal tube, presumed branching pattern of the arms, and cuneate brachials bear coarse ornamentation. These are all features of the stellarocrinids.

Family SUNDACRINIDAE Moore & Laudon, 1943

Sundacrinus Wanner, 1916

TYPE SPECIES. *Sundacrinus granulatus* Wanner, 1916 from the Permian Basleo Beds, Timor; by original designation.

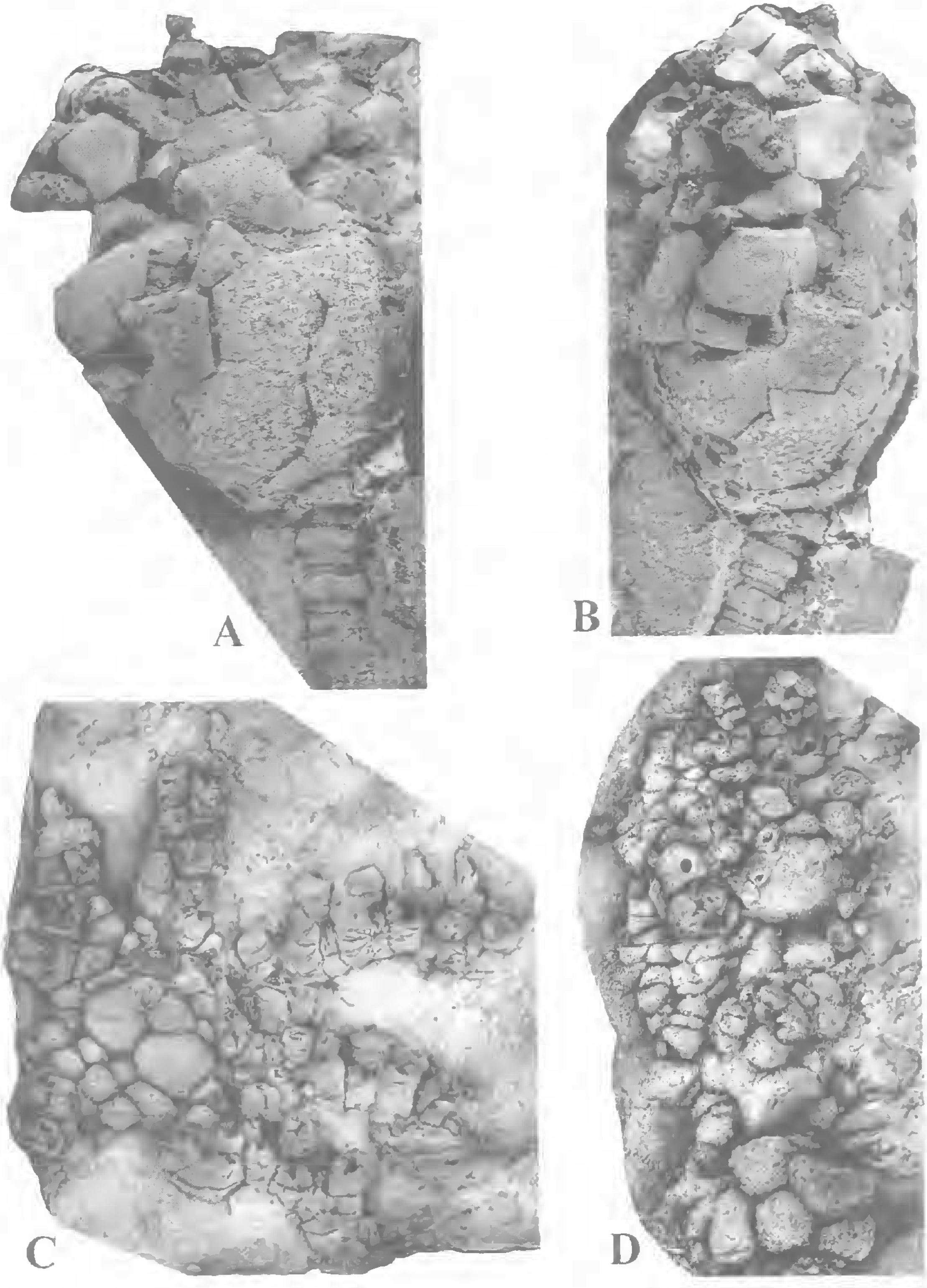
Sundacrinus medius sp. nov. (Fig. 13A,B)

ETYMOLOGY. Latin *medius*, middle; refers to the cup shape intermediate between that of 2 previously described species.

MATERIAL. QMF38908 from QML518.

DESCRIPTION. Crown medium size, pear-shaped, 32.4mm long (incomplete), 19.6mm wide. Cup medium to high bowl-shaped, 13mm long, 18.6mm wide at radial summit, base gently upflared, all plates very thick with coarse nodose ornament grading into irregular anastamosing ridges. Infrabasal circlet large, 9.5mm diameter, gently upflared, visible in lateral view. Basals largest plates in cup, gently convex longitudinally and transversely, widely flaring, of variable size and shape; posterior basal hexagonal, 7.5mm long, 8.4mm wide, adjoining radianal, BC basal, infrabasals, CD basal, D radial and anal X. Radials large, 6.5mm long, 7.5mm wide, subvertical to slightly incurved distally, weakly convex longitudinally and transversely. Radial facet plenary, strong outward-downward slope. Two pentagonal anals in cup; radianal largest, adjoining C radial, BC and CD Basals, anal X, and first tube plate, distal tip projecting slightly above radial summit; anal X adjoining radianal, CD basal, D

FIG. 13. A,B, *Sundacrinus medius* sp. nov., posterior and D ray views of holotype, QMF38908, ×2.6. C, Stellarocrinid? gen. et sp. nov., oral view of tegmen and arms, UQF12211A, ×1. D, *Moapacrinus cuneatus* sp. nov., posterior view of slightly disarticulated crown, holotype, QMF38909, ×1.9.


A
B
C
D

radial, D primibrach, and overlying tube plate, distal 1/3 above radial summit. D ray primibrach elongate, straight longitudinally, strongly convex transversely, may be axillary. Secundibrachs cuneate uniserial, elongate, deep, straight longitudinally, strongly convex transversely, with wide V-shaped ambulacral groove. Anal tube stout, projecting above cup, formed of thick hexagonal plates of uncertain structural pattern, probably laterally interlocked stacked columns, length unknown. Stem round transversely, 4.5mm diameter, heteromorphic, of variable noditaxis pattern in 24mm length preserved, at least 4 distinct sizes of columnals; latus moderately to strongly convex.

REMARKS. This partial crown consists of a slightly crushed cup below a jumbled pile of dislocated brachials and anal tube plates. It is assigned to *Sundacrinus* based on cup shape, thick plates, plenary radial facet sloping outward-downward and irregular shape of cup plates.

Sundacrinus medius has a cup shape intermediate between the conical cup of *S. triangulus* Wanner, 1924 and the bowl-shaped cups of *S. granulatus* Wanner, 1916 and *S. vastus* Wanner, 1924. The elongate cup of *S. elongatus* is much more slender than that of *S. medius*. Moore et al. (in Moore & Teichert, 1978) recognised that the number of anals in *Sundacrinus* varied, reporting 1, rarely 2. However, there are 2 in *S.* cf. *vastus* (Wanner, 1937, pl. 10, fig. 25) and 3 in *S. triangulus* (Wanner, 1937, pl. 10, fig. 21). Thus 2 anals in *S. medius* is intermediate.

This is the first report of the anal tube of *Sundacrinus* and the first report of the genus in Australia. It provides additional support for interconnections of E Australia and Timor.

Superfamily CROMYOCRINOIDEA Bather, 1890
Family CROMYOCRINIDAE Bather, 1890

Moapacrinus Lane & Webster, 1966

TYPE SPECIES. *Moapacrinus rotundatus* Lane & Webster, 1966 from the Artinskian part of the Bird Spring Formation, Nevada; by original designation.

Moapacrinus cuneatus sp. nov.
(Fig. 13D)

ETYMOLOGY. Latin *cuneatus*, wedge-shaped.

MATERIAL. HOLOTYPE: a crushed, partly disarticulated, partial crown, QMF38909 from QML518.

DIAGNOSIS. Crown elongate, cup medium bowl-shaped, shallow basal invagination, sutures impressed, coarse nodose ornament, single large anal, axillary 1st primibrach, brachials strongly cuneate.

DESCRIPTION. Crown elongate, 46.2mm long, incomplete. Cup medium bowl-shaped, 7.6mm long, 16mm wide, shallow basal invagination, sutures impressed, coarse nodose ornament, slightly incurved at radial summit. Infrabasal circlet not visible in lateral view. Basals large, 5.3mm long, 6.7mm wide, strongly convex longitudinally and transversely, forming base of cup and lower part of cup wall. Radials of intermediate size, 4.8mm long, 8.1mm wide, moderately convex longitudinally and transversely, subvertical. Radial facet plenary, deep; transverse ridge slightly concave externally; ligament pit elongate, deep; narrow outer margin; muscle fields large, intermuscular furrow shallow.

Single anal large, 4.5mm long, 5.2mm wide, directly above posterior basal, distal 2/3 above radial summit. Single primibrach axillary. Brachials uniserial, strongly cuneate, gently convex longitudinally, strongly convex transversely; 10 arms.

REMARKS. *Moapacrinus cuneatus* has wedge-shaped brachials and is ornamented with coarse nodes, whereas other species of the genus have rectilinear brachials and lack coarse nodose ornament. Pabian & Strimple (1993) reported fine granular ornament on *M. elexensis* Pabian & Strimple, 1993 known only from a cup. Only the posterior 1/2 of the cup of *M. cuneatus* is exposed; the C and D ray arms are dislocated and brachials partly disarticulated.

This is the first report of *Moapacrinus* outside North America, the first record of a cromyocrinid in E Australia, and the youngest cromyocrinid known. Cromyocrinids are common in late Palaeozoic faunas of the Midcontinent and Rocky Mountain regions of the USA. Pabian et al. (1989) reported the cromyocrinids in their 'Terrigenous Facies Belt', implying some clastic sediment entering the living environment. Webster & Houck (1998) noted that cromyocrinids dominate Late Carboniferous faunas in intermontane basin settings of the Rocky Mountain region. Although carbonates dominated the environment, some sand size clastic sediment was deposited wherein the cromyocrinids were living. Thus, a cromyocrinid was probably well adapted for living in the mudstone environment of the Condamine Beds.

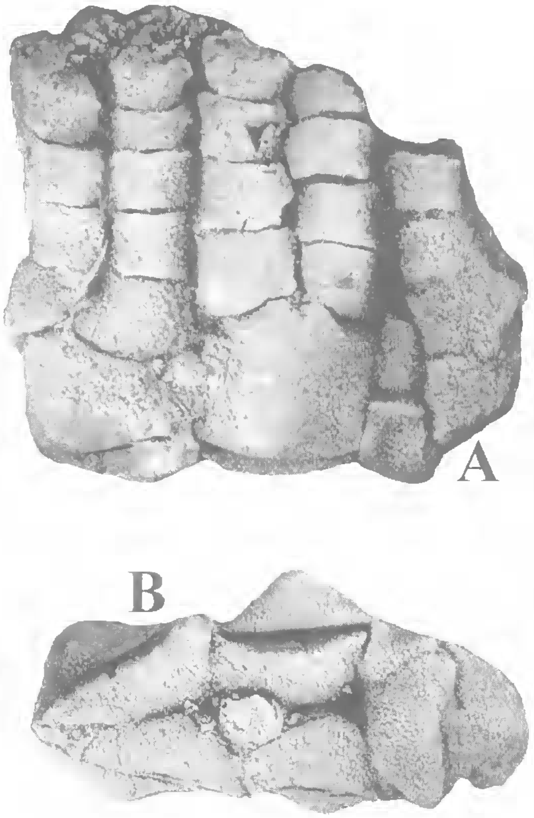


FIG. 14. A, B, *Parabursacrinus granulatus* Wanner, 1949, D ray and basal views of crushed crown QMF38882, ×3.2.

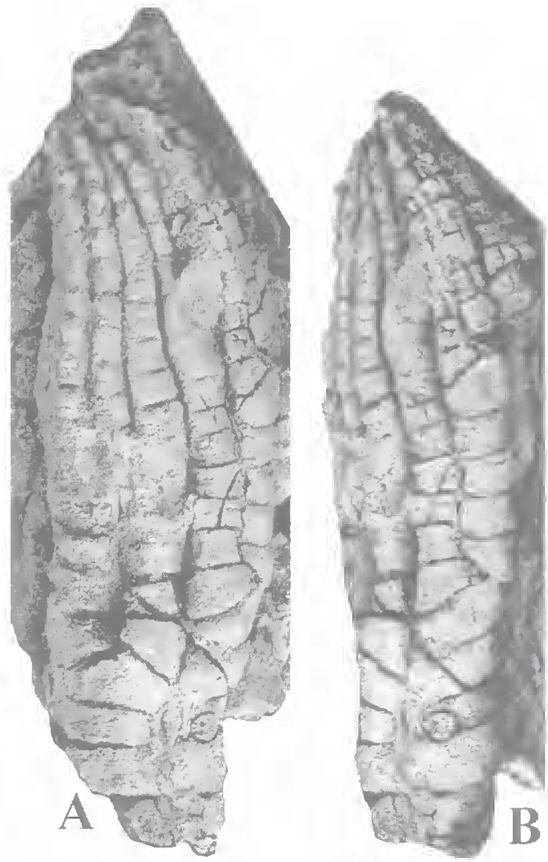


FIG. 15. A,B, Timorechinid gen. indet., lateral views of partial set of arms QMF38883, ×3.3.

Family INDOCRINIDAE Strimple, 1966

Eoindocrinus Arendt, 1981

TYPE SPECIES. *Eoindocrinus praerimosus* Arendt, 1981 from the late Artinskian Sarginsk Horizon, Ural Mts; by original designation.

Eoindocrinus praecontignatus Arendt, 1981 (Fig. 12A,B)

MATERIAL. External mould of cup, QMF38910 from QML518.

REMARKS. This small cup (5.4mm long, 5.8mm wide), on the arms of *Pedinocrinus? nodosus*, is oriented on its side with the C-D basal centred, the basal circlet upturned and the oral rim crushed downward (not visible). The large stellate ridge ornament converges in the centre of the basals and forms triangles across adjacent plates. Smaller inflated triangles are formed within these at the apices of triple plate junctions. A ridge junction also occurs on the radianal which supports the right tube plate distally and is adjacent to anal X.

A specimen of *E. praecontignatus* from the Wandagee Sandstone of Western Australia has partly developed secondary ridges forming a secondary triangle within the primary ridge triangle (Webster, 1990). The Condamine and Wandagee forms are considered conspecific with variation in ornament comparable to that in *E. praecontignatus* from the Urals (Arendt,1981).

Superfamily ZEACRINITOIDEA Bassler & Moodey, 1943
Family ZEACRINITIDAE Bassler & Moodey, 1943

Parabursacrinus Wanner, 1924

TYPE SPECIES. *Bursacrinus procerus* Wanner, 1916 from the Basleo Beds, Timor; by original designation.

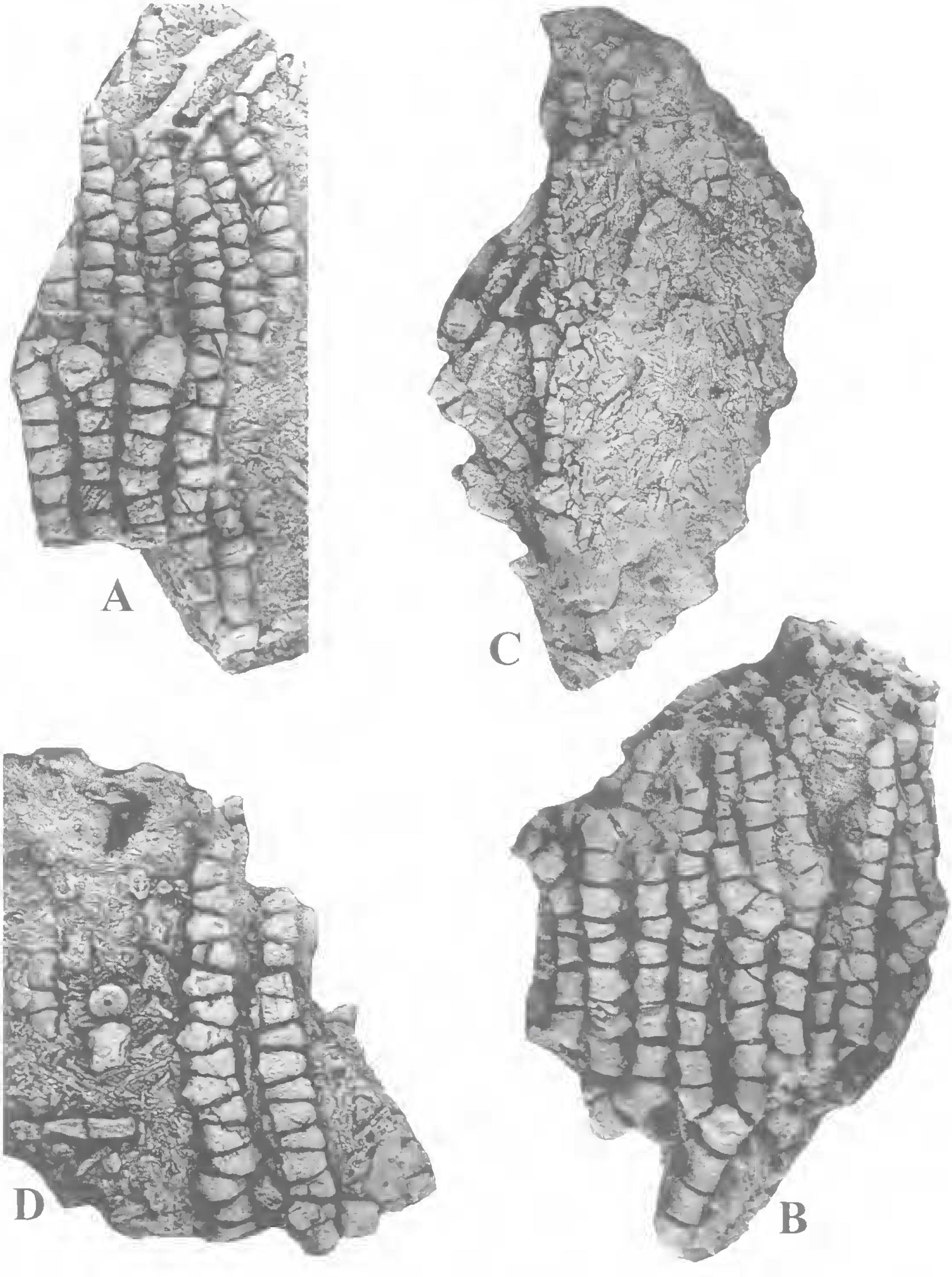


FIG. 16. A,B, Poteriocrinitid indet., arms 1. A, lateral view of QMF38885, ×3.2. B, lateral view of QMF38884, ×3.1. C,D, Poteriocrinitid indet., arms 3, interior (×3) and exterior (×4) lateral views of QMF38887, ×4.

Parabursacrinus granulatus Wanner, 1949
(Fig. 14)

MATERIAL. QMF38882 from QML1232.

REMARKS. This small crown is probably an immature or young adult. It is crushed against the C-EA axis, infrabasals and basals are not visible and distal parts of the arms are lost. The single anal projects 1/2 above the radial summit. Arms all bifurcate on the 1st primibrach. Granulose ornament continues onto the rectilinear brachials. Heteromorphic proximal stem columnals are round in section.

Family TIMORECHINIDAE Jaekel, 1918

Timorechinid gen. indet.
(Fig. 15)

MATERIAL. QMF38883 from QML1237.

DESCRIPTION. Arm fragment incomplete, slender, 32mm long, 13.5mm wide, parts of ', or possibly 4 rays present. Arms 3, slender. Brachials uniserial, rectilinear, gently convex longitudinally, moderately convex transversely. Isotomous branching on 4th and 5th brachials, again on 4th and 5th brachials on outer 1/2 of arm, probably endotomous. Pinnules and ambulacral groove not visible.

REMARKS. This specimen has the arms enclosed, is crushed, and probably represents parts of 3 rays. The main part visible is judged to represent 1 ray which had bifurcated isotomously below the preserved part. As interpreted there are 6 arms in the ray, total of 30 arms if all rays bifurcate uniformly. Brachials and arm branching pattern of this type occur in *Notiocrinus* and *Parabursacrinus* of the Timorechinidae to which the specimen is referred.

Poteriocrinitid indet., arms 1
(Fig. 16A,B)

MATERIAL. QMF38884 and 38885 from QML1237.

DESCRIPTION. Fragment 1. Arms slender, elongate; fragment 29.2mm long, 19.4mm wide, incomplete, including medial portions of a minimum of 16 arms with one additional distal branching on most arms. Brachials rectilinear to moderately cuneate, gently convex longitudinally, strongly convex transversely. Axillary brachials strongly protruded. One slender pinnule per brachial on alternate sides of arm. All branchings isotomous, but only branch on one half of arm distally, probably endotomous.

FIG. 17. Poteriocrinitid indet., arms 2, lateral view of QMF38886, ×1.8.

Fragment 2. 32mm long, 14mm wide, incomplete, medial portions of a minimum of 9 arms. Description as for fragment 1.

REMARKS. These 2 fragments may belong to a single specimen as they were found within 15 cm of one another. They are the medial and distal parts of the arms and, if from 1 specimen, there were a minimum of 40 arms. In the enclosed position the arms have a jointed or knotted appearance at the branchings, similar to those of several poteriocrinitids, such as *Abrotocrinus* and *Anchicrinus*.

Poteriocrinitid indet., arms 2
(Fig. 17)

MATERIAL. QMF38886 from QML1240.

DESCRIPTION. Partial set of arms 53.8mm long, 39.5mm wide, incomplete, arms unbranched, loosely parallel. Brachials medium size, moderately cuneate, straight to weakly convex longitudinally, roundly convex transversely, with pinnule on long end; ambulacral groove shallow, rounded V shape.

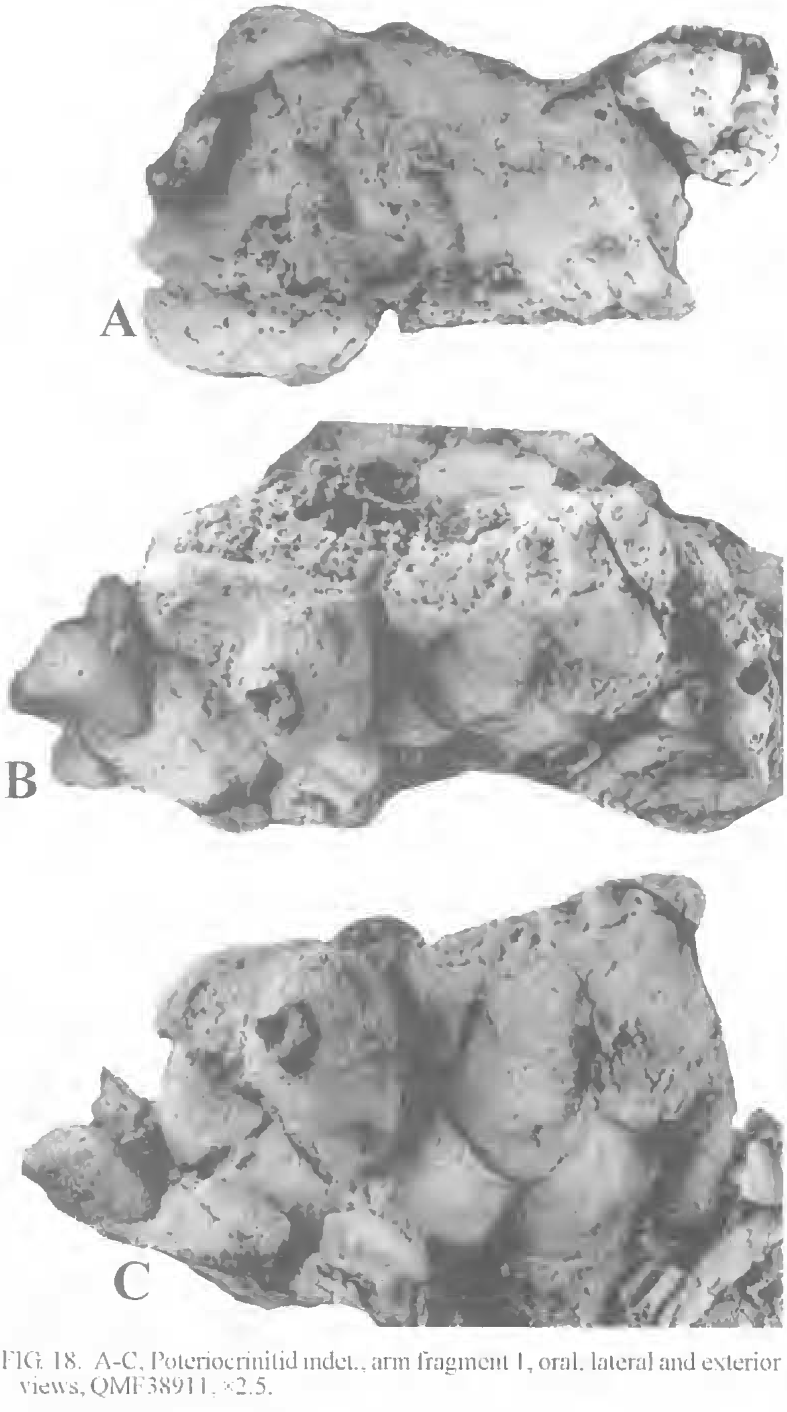


FIG. 18. A-C, Poteriocrinitid indet., arm fragment 1, oral, lateral and exterior views, QMF38911, ×2.5.

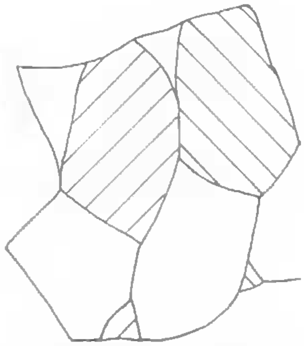


FIG. 19. Poteriocrinitid indet., arm fragment 1, camera lucida sketch of exterior surface of 4 brachials shown in Fig. 18C, ×3. Similar parallel ruled sections are external parts of a single brachial.

REMARKS. The arms have a slight zigzag appearance as a result of weathering, especially the long pinnule bearing end of the brachials with greater relief. Where there is little weathering the zigzag is slight. Nine arms are present on the 2 sides of the specimen. It is not known if the A ray was unbranched and there were only 9 arms or a 10th arm was lost with weathering. These arms are similar to a number of poteriocrinitids, especially some scytalocrinids and decadocrinids.

Poteriocrinitid indet.,
arms 3
(Fig. 16C,D)

MATERIAL. QMF38887 from QML1237.

DESCRIPTION. Arm fragment 30mm long, 17.9mm wide, with parts of 10 unbranched arms. Arms slender. Brachials uniserial, strongly cuneate, gently convex longitudinally, strongly convex transversely. Ambulacral groove wide, open rounded V-shaped. One slender pinnule per brachial on long end.

REMARKS. The specimen represents the distal part of a minimum of 10 arms, which may represent only 1/2 the arms of the specimen as the pinnules and interior of the arms are visible on 1 side of the small slab, the exterior of 4 arms on the other side and some arms between these are visible in end view.

Poteriocrinitid indet., arm fragment 1
(Figs 18, 19)

MATERIAL. QMF38911 from QML518.

DESCRIPTION. Fragment, very large 29.2mm long, 25.2mm wide, 10.5mm deep, consisting of 8 brachials. Single brachial 7.8mm long, 25.2mm wide, 10.5mm deep. Brachials uniserial but appearing biserial (=pseudobiserial). In exterior view each brachial divided into 2 parts; larger pentagonal section borders 2 adjacent brachials in middle of arm in apparent biserial interlocking fashion, sides adjoining 2 pentagonal sections of alternate brachials, end forming arm margin with pinnule facet; smaller section triangular, longer isosceles sides tapering toward centre of arm, adjoining adjacent brachials on either side, shorter 3rd side forming arm margin with pinnule facet. Both sections convex longitudinally and transversely, continuous beneath the 2 adjacent brachial sections. Interior convex with central small V-shaped ambulacral groove.

REMARKS. These brachials are the largest known for Palaeozoic crinoids, the only known pseudobiserial form, and one of the few bipinnular forms, bearing one pinnule on each end of a compound brachial. The bipinnular condition of *Zeacrinus* is a minimal form of hyperpinnulation. Hyperpinnulation, in which multiple pinnules are present on both sides of the arms, developed in a few camerates (*Briarocrinus*, 4 per brachial, 2 on each side) and poteriocrinitids (*Cupressocrinites*, 6 or 8 per brachial, 3 or 4 on each side; *Neozeacrinus*, 4 per brachial, 2 on each side). Hyperpinnulation is thought to have developed by fusion of adjacent brachials (Ubaghs in Moore & Teichert, 1978).

Development of the pseudobiserial form requires overlapping of the 2 adjacent brachials, as well as the bipinnular condition. The following possible origins are suggested. First, that they evolved by fusion of 2 cuneate uniserial brachials, one becoming the shorter end and the other the longer end, each bearing a pinnule, with simultaneous overgrowth of the 2 adjacent brachials. Second, that they evolved from biserial brachials in which 2 pinnule bearing brachials fuse at the midline with the simultaneous overgrowth of the 2 adjacent brachials. Third, that they evolved from cuneate brachials with development of a pinnule on the short non pinnule bearing end of a brachial, concurrent with overgrowth of the 2 adjacent brachials. The 1st or 2nd origin is most likely as the 3rd requires redevelopment of a pinnule on a non pinnule bearing end of a brachial.

Although no pinnules are attached to the brachials, 2 ossicles adjacent to the arm fragment are pinnulars, both with the wide V-shaped ambulacral groove exposed. The largest is 5mm long, 5mm wide and 3.5mm deep; the ambulacral groove is 1.5mm wide and 0.6mm deep. Their size and association with the arm fragment suggest that they belong to 1 species.

Poteriocrinitid indet., arm fragment 2
(Fig. 20B,C)

MATERIAL. QMF38912 from QML518.

DESCRIPTION. Arm large, 59mm long (incomplete), unbranched. Brachials large, (proximal brachial 4mm long on wide end, 7mm deep, estimated 8mm wide) strongly cuneate, biserial proximally, uniserial distallly, straight to gently convex longitudinally, strongly convex transversely, with large pinnule on wide end, ambulacral groove large, V-shaped. Proximal pinnule 3mm long, 4mm deep, concave longitudinally, strongly convex transversely. More distal pinnules slender, elongate, concave longitudinally, strongly convex transversely.

REMARKS. This arm fragment is curved backwards in a feeding or death posture. Pinnules are larger than brachials of many crinoids. It probably belongs to an unknown poteriocrininid.

Poteriocrinitid indet., arm fragment 3
(Fig. 20A)

MATERIAL. QMF39013 from QML518.

DESCRIPTION. Brachials large, 3.3mm long, 4.8mm wide, moderately cuneate, slightly convex longitudinally, strongly rounded transversely, coarse nodose ornament; single pinnule on long end, pinnulars slender, elongate. Anal tube slender, formed of irregularly arranged polygonal plates with coarse nodose ornament; basal plate of tube with sharply pointed centrally expanded spine.

REMARKS. The nodose ornament is randomly distributed externally with up to 20 on a single brachial. Nodose brachials occur in several Condamine fauna species. Nodes are more numerous and smaller on Poteriocrinitid indet., arm fragment 3 than on *Pedinocrinus*? *nodosus* and coarser than on *Poteriocrinites*? *smithii* Etheridge, 1892.

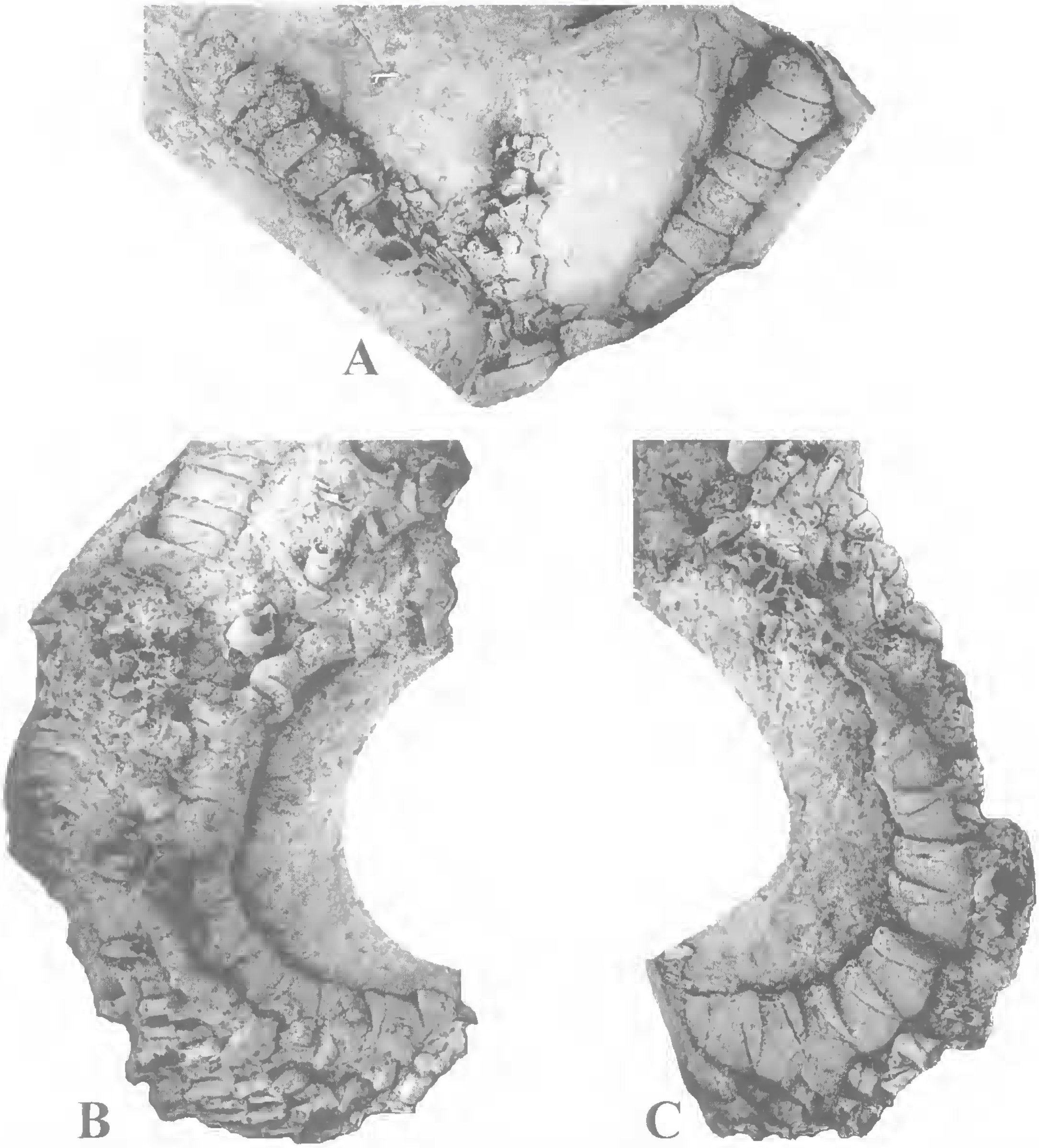


FIG. 20. A, Poteriocrinitid indet., arm fragment 3, lateral view, QMF39013, ×2. B,C, Poteriocrinitid indet., arm fragment 2, counterpart lateral views, QMF38912, ×1.7.

Subclass FLEXIBILIA Zittel, 1895
Order SAGENOCRINIDA Springer, 1913
Superfamily LECANOCRINOIDEA Springer, 1913
Family MESPILOCRINIDAE Jaekel, 1918

Loxocrinus Wanner, 1916

TYPE SPECIES. *Loxocrinus globulus* Wanner, 1916 from the Basleo Beds, Timor, by original designation.

Loxocrinus booni Marez Oyens, 1940
(Fig. 21E,F)

MATERIAL. QMF38888 from QML759.

REMARKS. This partial cup consists of the D and E radials and distal tip of the DE basal, if the A radial is symmetrical. The cup is low bowl-shaped with the infrabasals probably not visible in lateral view. It is slightly abraded and encrusted with bryozoans. Radial facets of the short, thick radial plates are shifted to the right of centre with the left shoulder wider than the right. The facets are concave, deep with a narrow rim of crenulae and culmina along the rounded outer edge; other details of the surface are lost by solution or covered by encrusting organisms.

Only *L. booni* has a low bowl-shaped cup with the infrabasals not visible in lateral view, as the other 2 species, *L. globulus* Wanner, 1916 and *L. dilatatus* Wanner, 1916, are globose with the infrabasals visible in lateral view.

Loxocrinus sp. 1
(Fig. 22A)

MATERIAL. QMF38889 from QML757.

DESCRIPTION. Radial small, 5mm long, 5.1mm wide, thick, proximally straight longitudinally, distally incurved, moderately convex transversely, fine granular to vermiform ornament; shoulders extended longitudinally, left shoulder wider than right, both wrapping around radial facet to ambulacral groove. Radial facet angustary, skewed right of centre, elliptical in outline, concave with marginal rim; transverse ridge aboral of centre, low; ligament pit in centre of radial, small, transversely elongate; outer marginal area crescent-shaped; muscle areas large, with irregular surface; ambulacral groove moderately wide V shaped, confined to adoral edge of facet.

REMARKS. If the radial facet of *Loxocrinus* sp. 2 were horizontal, the radial sloped inward for its entire length. Most likely the radial facet sloped downward, outward and the proximal part of the radial was vertical with the distal part curving inward. The shoulders left small obvious notches between arm bases. The specimen is the D or E radial if the A radial is symmetrical.

Loxocrinus sp. 2
(Fig. 22B,C)

MATERIAL. QMF38890, 38891 from QML758.

DESCRIPTION. Radial small, thick, proximally straight longitudinally, distally incurved, moderately convex transversely, unornamented; shoulders extended longitudinally, left shoulder wider than right, wrapping around radial facet to ambulacral groove, right shoulder terminating against radial facet adoral of transverse ridge. Radial facet angustary, skewed right and left of centre, nearly circular in outline with extended right side muscle area, concave with marginal rim; elevated transverse ridge 3/4 of distance aboral of facet; ligament pit aboral of centre of and culmina on aboral 1/2; muscle areas large, irregular surface; ambulacral groove moderately wide V-shaped, notched into adoral 1/4 of facet. QMF38891 8.1mm long, 7.6mm wide; QMF38890 8.2mm long, 10.1mm wide.

REMARKS. Orientation of *Loxocrinus* sp. 2 would have been very similar to *L.* sp. 1. The two forms are distinguished by the lack of ornamentation on *L.* sp. 2. They both differ from *L. booni* by being much longer. QMF38891 is the D or E radial, if the A radial is symmetrical, as the facet is skewed to the right and the facet shows evidence of solution weathering. QMF38890 is the B or C radial with the facet skewed to the left.

Family PROPHYLLOCRINIDAE Moore & Strimple, 1973

Prophyllocrinus Wanner, 1916

TYPE SPECIES. *Prophyllocrinus dentatus* Wanner, 1916 from the Basleo Beds, Timor; by original designation.

Prophyllocrinus sp. 1
(Fig. 21A)

MATERIAL. QMF38892 from QML758.

DESCRIPTION. Radial medium size, 10.8mm long (incomplete), 10.4mm wide, medium depth, proximally straight longitudinally, distally incurved, moderately convex transversely, fine granular ornament; shoulders greatly extended longitudinally, left shoulder wider than right, extending slightly beyond radial facet, right shoulder broken off, probably terminating against distal end of radial facet. Radial facet angustary, skewed right of centre, elongate U-shaped, concave with marginal rim; elevated transverse ridge 3/4 aboral length of facet; ligament pit small, centre of radial; outer marginal area crescent-shaped; muscle areas large, shallowly concave; ambulacral groove deep, wide V-shaped, notched into adoral 1/2 of facet.

REMARKS. Solution etching has destroyed the proximal edge of the radial and some surface features of the transverse ridge and ligament pit of the radial facet. The right shoulder and a small piece of the left edge of the outer margin of the radial facet were broken off. The long U-shaped radial facet readily distinguishes the specimen from those of *Loxocrinus* and allies it with *Prophyllocrinus*. Breakage suggests a very short right shoulder, a character of *Proapsiocrinus* and *Ancistrocrinus*.

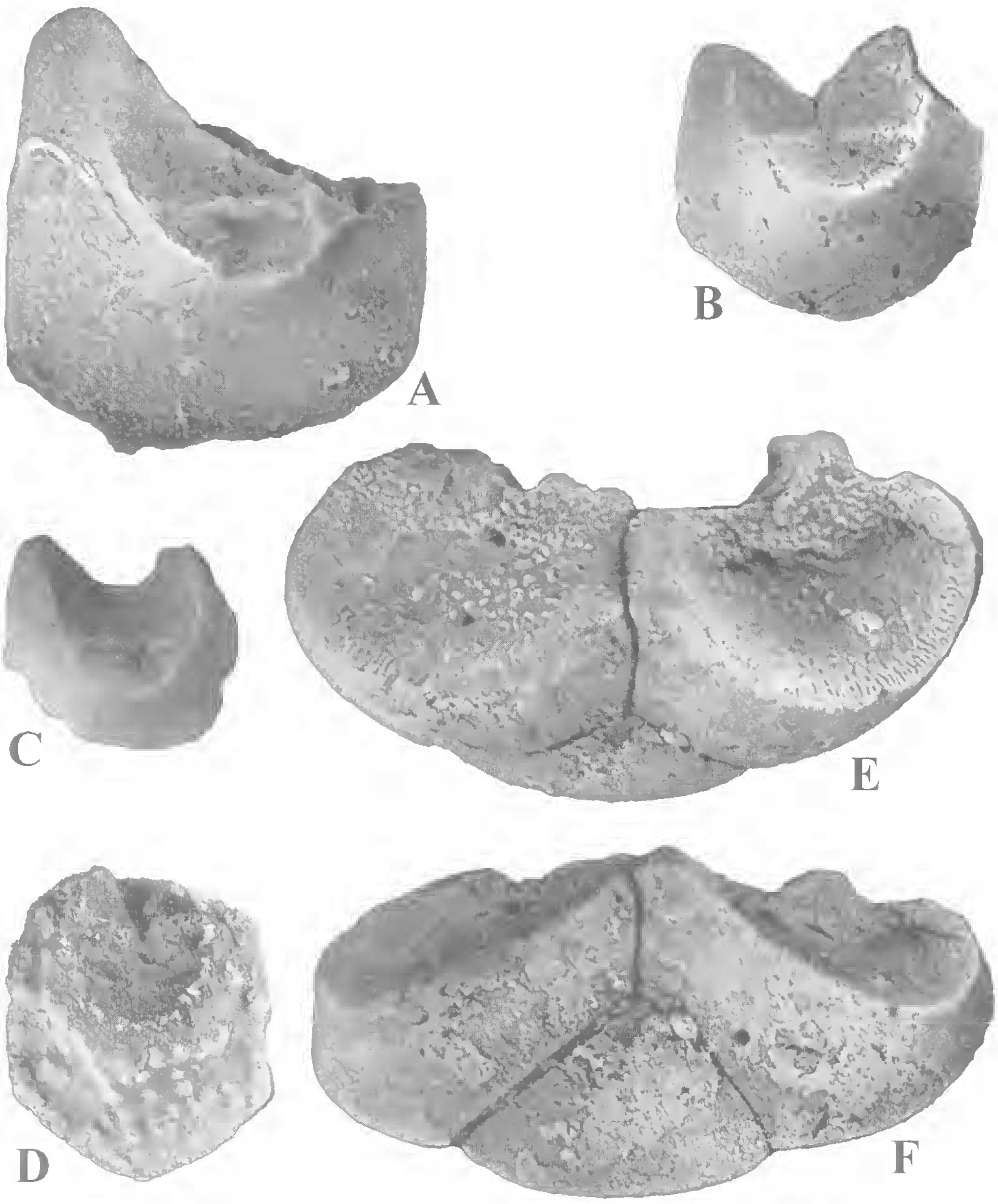


FIG. 21. A, *Prophyllocrinus* sp. 1, lateral view of radial QMF38892, ×5.7. B,C, *Prophyllocrinus* sp. 2. B, lateral vieof radial QMF38893, ×4.4. C, lateral view of radial QMF 38894, ×4.1. D, *Prophyllocrinus* sp. 3, lateral view of radial QMF38895, ×9.2. E,F, *Loxocrinus booni* Marez Oyens, 1940, oral and lateral views, QMF38888, ×5.5.

Prophyllocrinus sp. 2
(Fig. 21B,C)

MATERIAL. Radials QMF38893 from QML758 and QMF38894 from QML757.

DESCRIPTION. Radial medium size and thickness, proximally straight longitudinally, distally incurved, moderately convex transversely, no ornament; shoulders greatly extended longitudinally, left shoulder longer than right, both terminate against distal end of radial facet. Radial facet angustary, skewed right of centre, elongate U-shaped, concave with marginal rim; elevated transverse ridge 3/4 aboral length of facet; ligament pit very small, centre of radial; outer marginal area crescent-shaped; muscle areas large, shallowly concave; ambulacral groove deep, wide V-shaped, notched into adoral 1/2 of facet. QMF38893 10.3mm long (incomplete), QMF38894 8mm long, 7.9mm wide (both incomplete).

REMARKS. QMF38893 lacks the distal end of the right shoulder, the proximal edge of the radial and adoral edge of the ambulacral groove from solution etching. Solution etching has destroyed the proximal edge of the radial, some surface features of the transverse ridge and ligament pit of the radial facet and distal parts of the muscle area and ambulacral groove of QMF38894. *Prophyllocrinus* sp. 2 differs from *P.* sp. 1 by lacking ornament.

Prophyllocrinus sp. 3
(Fig. 21D)

MATERIAL. QMF38895 from QML758.

DESCRIPTION. Radial small, 4.9mm long, 4.6mm wide, medium depth, proximally straight longitudinally, distally incurved, moderately convex transversely, with coarse granular ornament; shoulders greatly extended longitudinally, left shoulder longer than right. Radial facet angustary, skewed right of centre, elongate U-shaped, concave with marginal rim; elevated wide transverse ridge located close to ambulacral groove at 1/3 adoral length of facet; ligament pit very small; outer marginal area crescent-shaped; muscle areas small, shallowly concave; ambulacral groove narrow V-shaped, notched into adoral 1/3 of facet.

REMARKS. Solution etching has destroyed the distal end of the right shoulder and some surface features of the transverse ridge. *Prophyllocrinus* sp. 3 differs from *P.* sp. 1 and *P.* sp. 2 by the coarse granular ornament. The specimen is probably a juvenile and with growth would have a facet much like that of *P.* sp. 1 or *P.* sp. 2.

Sagenocrinitid indet.
(Fig. 22D)

MATERIAL. QMF38896 from QML1233.

REMARKS. A weathered, poorly preserved, partial crown of an indeterminate sagenocrinitid shows part of the cup plates, part of one ray including an interbrachial series of 2 plates, and distal brachials of 2 or 3 rays. Critical parts of the cup, if preserved are not exposed to identify the genus. This is the first crown of a sagenocrinitid reported from the Callytharra Formation. It is illustrated to show the faunal diversity.

Loose flexible ossicles perhaps belonging to this taxon, are uncommon in bulk samples of the Callytharra Formation from the type section. Both cup and arm ossicles are present and the brachials show well-developed patelloid processes.

Subclass ARTICULATA Zittel, 1879

The Articulata is revised to include 8 orders, 7 as in the Treatise (Moore & Teichert, 1978) plus Ampelocrinida below. Articulata are characterised by brachial pairs with alternating muscular and cryptosyzygial articulation.

Order AMPELOCRINIDA ord. nov.

REMARKS. The Ampelocrinida (Table 2) includes Corythocrinidae, Tribrachyocrinidae, Calceolispongiidae, Ampelocrinidae (as constituted below) and the unassigned *Tasmanocrinus*. It may be defined as Palaeozoic genera not previously included in the Articulata but with brachial pairs with alternating muscular and cryptosyzygial articulation and lacking perfect pentameral symmetry.

Family AMPELOCRINIDAE Kirk, 1942

DIAGNOSIS. Cup bowl-shaped to discoidal, small; infrabasals small, subhorizontal to downflaring, commonly not visible in lateral view; 1 anal (exception, 3 in *Ampelocrinus*); radial facets plenary; arms commonly 10, rarely more, 2 primibrachs (exception, 3-4 in *Halogetocrinus*); isotomous branching; cuneate pinnulate brachials ; brachial pairs with alternating muscular and cryptosyzygial articulation; short anal tube where known (exception, recurved in *Ampelocrinus*); proximal stem commonly pentagonal or subpentagonal, rarely circular, in transverse section; very cirriferous close to cup where known.

GENERA INCLUDED. *Ampelocrinus*, *Chlidonocrinus*, *Cymbiocrinus*, *Halogetocrinus*, *Moundocrinus*, *Oklahomacrinus*.

REMARKS. Some species assigned to these genera may not belong to the Ampelocrinidae but a review of them is beyond the scope of this study. Genera assigned to the Ampelocrinidae by Moore et al. (in Moore & Teichert 1978), here excluded are *Arroyocrinus*, *Polusocrinus*,

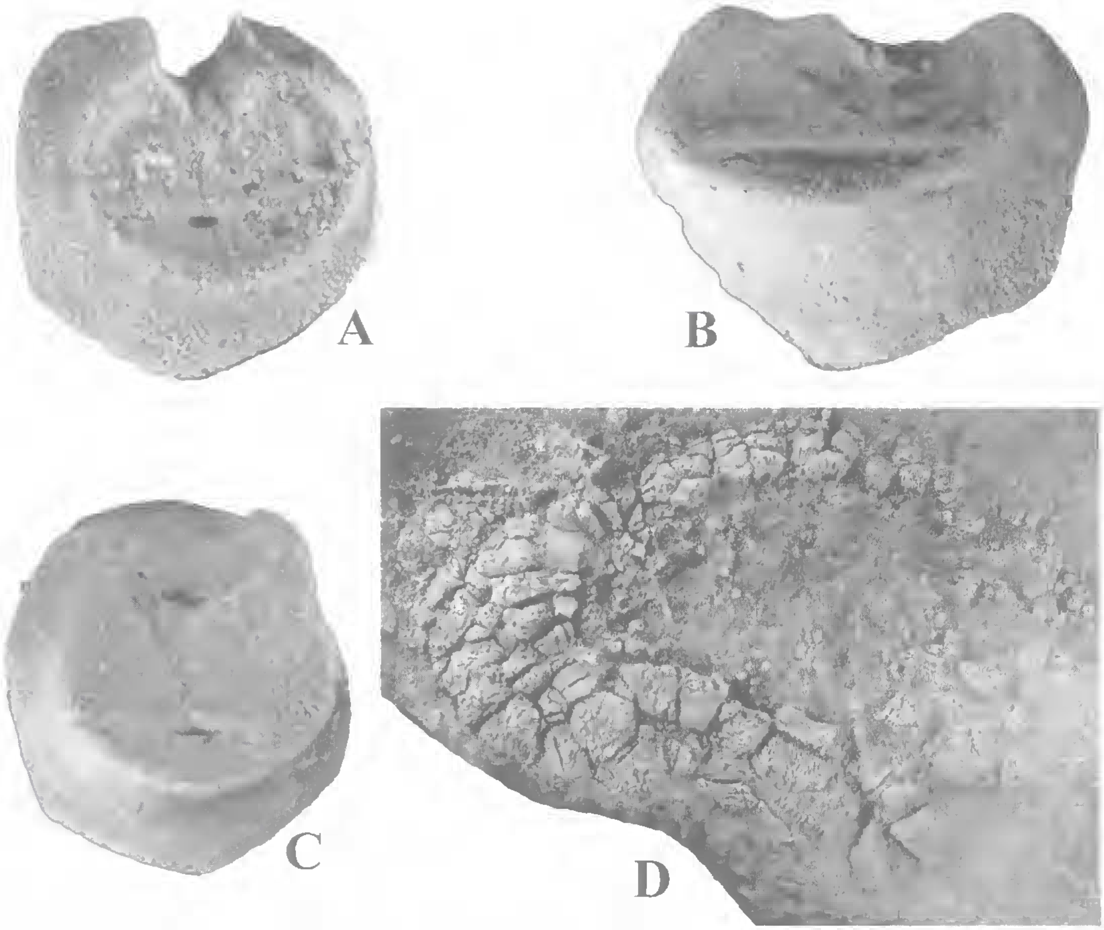


FIG. 22. A, *Loxocrinus* sp. 1, lateral view of radial QMF38889, ×9.4. B,C, *Loxocrinus* sp. 2. B, lateral view of radial QMF38890, ×5.8. C, lateral view of radial QMF38891, ×5.8. D, Sagenocrinitid indet., lateral view of weathered crown QMF38896, ×1.7.

Proampelocrinus, *Spheniscocrinus*, because they lack the brachial pairs with alternating muscular and cryptosyzygial articulation. Inclusion of some cymbiocrinids within and exclusion of some ampelocrinids from the Ampelocrinidae requires revision of both families, a revision beyond the scope of this paper. Ampelocrinidae are intermediate to upper tier feeders, adapted to carbonate or clastic substrates in equatorial latitudes.

Family CALCEOLISPONGIIDAE Teichert, 1954

DIAGNOSIS. Bowl-shaped to cylindrical cup; thick plates; basals often extended as prongs or spines; 1 anal; radial facets plenary; arms 5 or more; 2 primibrachs if arms not atomous; isotomous branching; brachials cuneate; brachial pairs with alternating muscular and cryptosyzygial articulation; pinnulate; arms incurling distally when enclosed; no tegmen; stem subpentagonal or pentagonal proximally, commonly becoming circular distally; cirriferous near cup where known.

GENERA INCLUDED. *Calceolispongia*, *Allosocrinus*, *Jimbacrinus*, *Metacalceolispongia* gen. nov.

REMARKS. The calceolispongiids are best characterised by their thick plates, bowl-shaped or cylindrical cup, often with extended prongs on the basals and distally incurled arms. They are a bottom or very low tier feeding animal adapted to a carbonate or clastic environment in equatorial and higher latitudes.

Calceolispongia Etheridge, 1915

TYPE SPECIES. *Calceolispongia hindei* Etheridge, 1915 from the late Artinskian upper Noonkanbah Formation, Canning Basin, WA; by monotypy.

REMARKS. Two major papers by Teichert (1949) and Willink (1979b) described most of the 22 species of *Calceolispongia* from Australia. Teichert (1949) described 12 species from Western Australia and demonstrated their stratigraphic value in the Carnarvon and Canning Basins. He reported that one of the major evolutionary trends of the genus was towards enlargement of the basals which were used for resting on, or anchoring within, the substrate in adult stages. The stem of these forms was a tether in the immature stages and so small as to be of no or little functional value in the adult stage (Webster,1990). Willink (1979b) described 7 species, reassigned 2 species questionably assigned to *Phialocrinus* by Etheridge (1892) to *Calceolispongia*, and proposed an evolutionary lineage for the E Australian taxa. He based his lineage largely on the basals and 2nd brachials. Although E Australian species include forms with nodose ornamented or thick, slightly to moderately enlarged bulbous basals, they never developed the extremely enlarged bulbous basals typical of the youngest WA species. The oldest WA species are quite small and have slightly to moderately enlarged basals (Teichert, 1949).

Willink (1979b) considered that E Australian species evolved separately from the WA species. The earliest forms of both E Australian and WA lineages began in the Sakmarian. It is of more than passing interest that the 8 non Australian taxa of *Calceolispongia*, known from the Basleo deposits of Timor (Wanner, 1916, 1924, 1937; Marez-Oyens, 1940), and 1 from the Artinskian deposits of peninsular India (Reed, 1928) are all the greatly enlarged basal type. This suggests that the WA, Indian and Timor forms all developed in an interconnected area of the Tethys and were geographically isolated from the E Australian taxa.

Willink (1979b) also described in detail the brachial muscle and ligament structure and proposed a 2 dimensional rheophilic feeding fan for species of *Calceolispongia* with only slightly to moderately enlarged bulbous basals. This was based on a stemmed form supposedly elevated off the substrate. He compared the arms to some modern crinoids noting their similarity of brachial and muscle structure. This same basic arm structure is present, where known, on all species of *Calceolispongia*, whether the cup is a greatly enlarged or slightly to moderately enlarged basal form. This implies that the feeding strategy of the greatly enlarged basal cup form, living on or partially buried within the substrate, and the slightly to moderately enlarged basal cup form, elevated off the substrate by the stem, was the same. We suggest that the slightly to moderately enlarged basal form was not elevated significantly above the substrate. Instead we interpret it to have had a runner-like stem, with the proximal end upturned so that the cup was in a position very similar to, but perhaps slightly higher than, the cup with a vestigal tether stem. The slightly to moderately enlarged and nodose basals of the stemmed form helped hold the cup in an upright or inclined position, preventing overturning and fouling of the arms in the substrate.

The 2nd brachial, where known, of all species of *Calceolispongia* has protruded nodes to short blunt spines or coarse irregular ridges. This includes the extremely enlarged or slightly to moderately enlarged basal forms of the taxon. Willink (1979b) suggested that these enlarged brachials: 1, added weight to the crown enabling the cup to orient on its side in slower currents; 2, acted as stabilisers if the crown was suddenly bent in strong currents or detached and oriented on it side; and 3, would have produced considerable enhancing eddying particulate feeding when the cup was oriented horizontally.

We agree with Willink's analysis of the plate, muscle, and ligament structure of the arms of the calceolispongiids, but, in part, question the functional significance of the nodes, blunt spines, or irregular ridges on the 2nd brachial and feeding model. The added plate material of the enlarged 2nd brachial to the overall weight of the crown would be minimal, as they account for a small percentage of the overall bulk of the crown. In a detached crown the nodes or blunt spines could serve to stabilise the crown by projecting into the substrate, but this would normally require the 2nd brachials of 2 rays. With the nodes protruded into the sediment it would severely limit, if not completely negate, the function of the rest of those 2 arms, limiting the filtration fan to 3 rays. In soft sediment the base of the ambulacral trackways would probably be fouled by burial in sediment.

It is very doubtful that the crown commonly survived if detached from the stem. Autotomy of the stalk of Palaeozoic crinoids has been discussed by Donovan (1993) and Baumiller (1997).

Although the ability to autotomise the stalk developed in late Palaeozoic cladids (*Paragassizocrinus*, Webster & Lane, 1970; among others), it has not been demonstrated that other taxa could regenerate the distal stem and reattach. If they autotomised the distal parts of the stem and then grew additional stem proximally, living by grasping or burial attachment of the cirri, it should be recognised by finding a stem preserved with the cirri in the grasping or burial position and the distal end autotomised. The only regenerated stems reported from the late Palaeozoic are those of a flexible crinoid (Strimple & Frest, 1979) and *Lichenocrinus* (Ausich & Baumiller, 1993).

Use of the nodes or spines to produce eddy currents useful for feeding is considered minimal. Because the arms project outwards away from the cup into the current, only the proximal part of the arms could have benefitted if the calceolispongiids fed in a 2 dimensional or normal parabolic filtration fan posture.

The projections on the 2nd brachial of both greatly enlarged and slightly to moderately enlarged basal cups suggest that they served a vital function necessary to either a stemmed existence with the cup barely elevated above the substrate (slightly to moderately enlarged basals, runner type stem) or the cup resting on, or partly buried within, the substrate (greatly enlarged basals, stem vestigal in mature forms). We suggest that the nodes or blunt spines served a dual purpose, as stops and protection, and that the feeding posture was similar in both types of calceolispongiid cup.

As stops, the nodes and spines prevented the continued rotational movement of the arms as they opened to feed. On forms with the basals buried within the sediment the nodes or spines could have stopped against the sediment or abut against another organism living in close proximity. The first brachial on *C. abundans* had to rotate outward 76° from a vertical position for the nodes on the brachial above the outer ligament pit to stop against the distal tip of the radial external to the ligament pit on the radial facet. The nodes or spines of the 2nd brachial would have to rotate 135° to abut against the proximal parts of the radials and distal parts of the brachials. With the immovable ligamentary articulation between the 1st and 2nd brachials (Willink, 1979b) it is impossible for the nodes or spines to abut the cup plates. However, they could abut against adjacent organisms and deter predators nipping at the base of the arms in cups with the basals resting on the substrate or cups barely elevated above the substrate on a runner stem. In either of these positions the proximal brachials would be elevated above the substrate and the arms spread in a narrow to widespread filtration fan or they could have spread into a subhorizontal feeding position with pinnules elevated into the current.

Teichert (1949, pl. 8, fig. 2) illustrated the oral view of a crown of *C. abundans* with the proximal part of the enrolled portion of the arms unrolled along the bedding surface. The first 2 brachials are buried in the sediment at a high angle to the more distal brachials, with only the distal part of the 2nd brachial partly visible at the base of the arms. The cup is completely buried. We interpret this specimen to have been in the feeding posture at the time of rapid burial followed by death. If the specimen died before burial, any current (such as that necessary to bury the specimen in sand) would have moved the arms into a semi-aligned postion, if not broken them off. This suggests that the enlarged basal calceolispongiid species, with the cup resting on or buried within the sediment, fed with the arms extended along the substrate rather than above the substrate up in the current in a 2 dimensional or normal parabolic filtration fan posture. The enrolled arms in the nonfeeding position prevented sediment from fouling the inactive ambulacral trackways and removed the arms from the paths of predators and benthic scavengers.

This also explains the relatively large space in the muscle area between the radial and 1st brachial facets (Willink, 1979b, fig 11) in the relaxed and flexed positions. Most cladid crinoids have relatively small spaces between the radial and 1st brachial facets when closed (muscle contracted) and larger spaces when open (muscle relaxed), because the muscle area of the radial facet is subhorizontal. The facet of the radial is steeply downflared into the cup of *Calceolispongia*, while the brachial facet is subhorizontal with the arm in the enrolled contracted position, not the relaxed position as shown by Willink. In the relaxed position the arm is unrolled and extended out into the feeding position with the ligament in the outer ligament pits of the radial and 1st brachial contracted. In both conditions the cross-sectional area between the muscle areas of the facets is relatively larger than in most poteriocrininids.

When closed the arms of the calceolispongiids

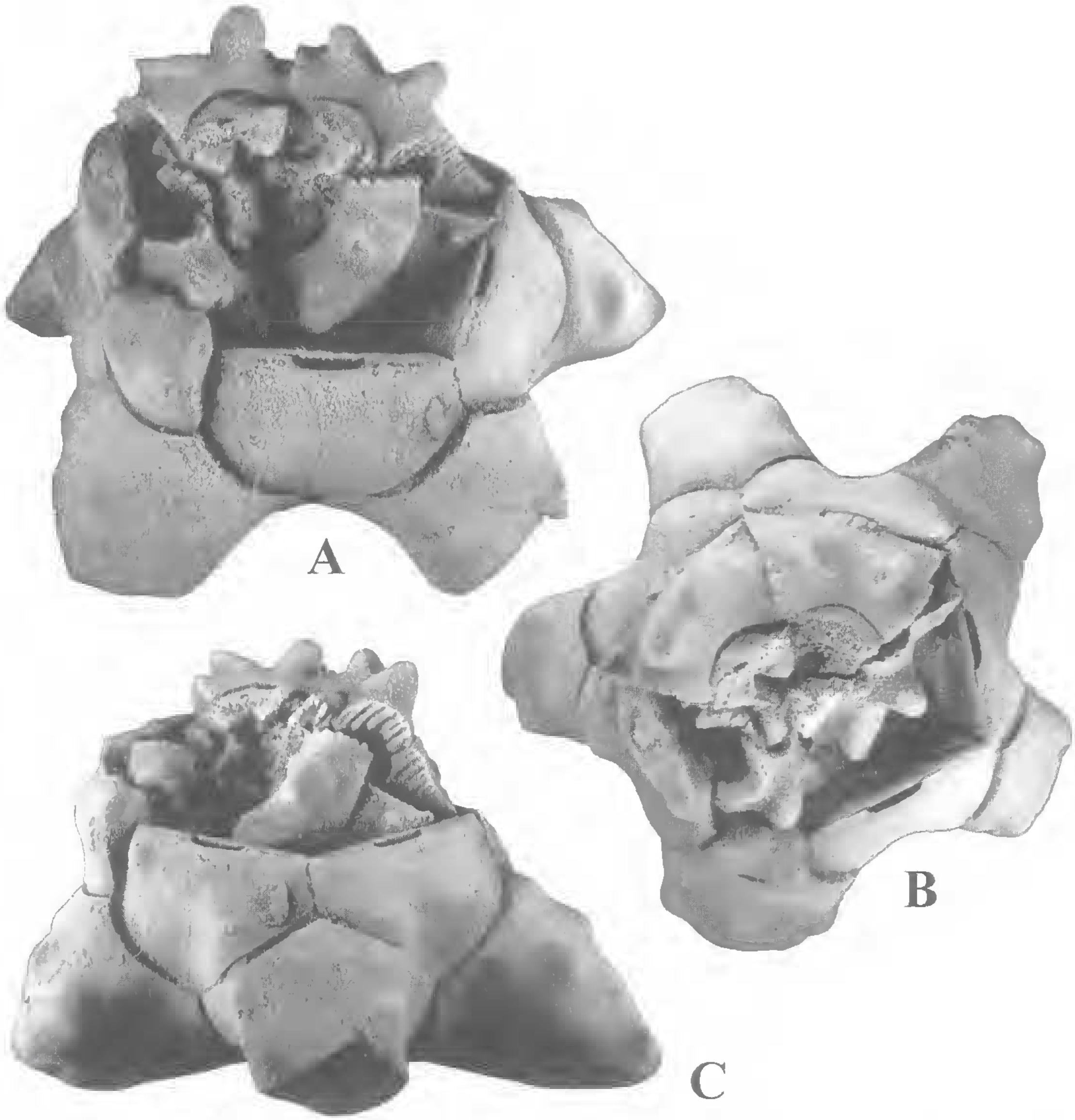


FIG. 23. *Calceolispongia abundans* Teichert, 1949, oblique C ray (A), distal (B) and B-C interray (C) views of partial crown QMF38874, ×2.3.

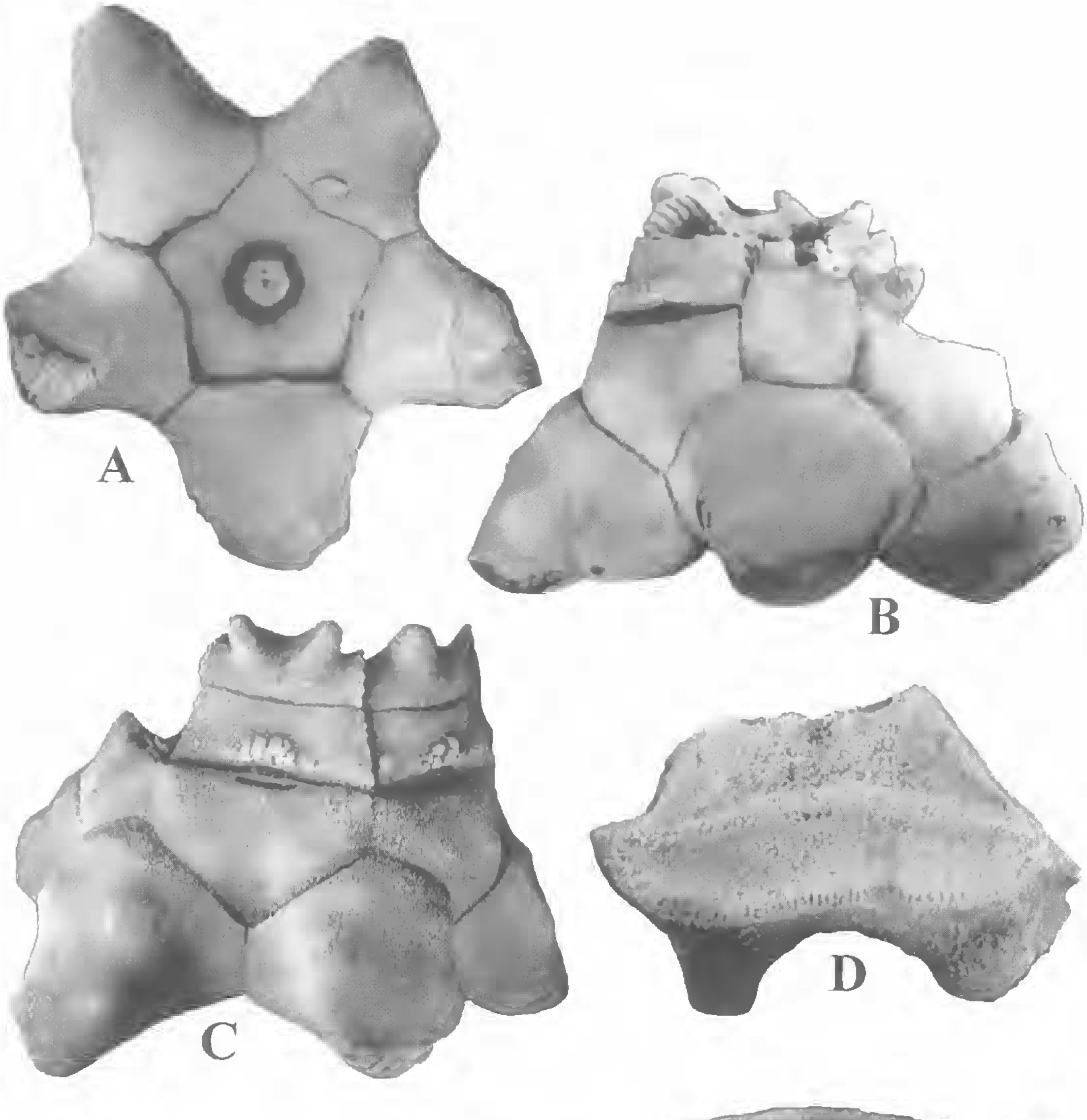
formed an open pentagonal petaloid structure in distal view, not the tightly enclosed crown of most poteriocrininids. However, the 1st and 2nd brachials were more tightly enclosed, surrounding the visceral mass protruded above the radial summit in the tegmen. The base of the enrolled arms formed a constriction, the arm girdle (Lane & Webster, 1966), above the 2nd brachial.

Another use of the node or spines on the 2nd brachial could have been to deter settlers from using the shelf developed atop the 2nd brachial and deny predators access to the visceral mass.

Calceolispongia abundans Teichert, 1949
(Figs 23, 24A-C)

MATERIAL. QMF38874 from QML1217.

REMARKS. The partial crown, an immature specimen (24mm long, 33mm maximum width), lacks the stem, tips of the protruded part of 4 basals and all distal parts of the arms beyond the



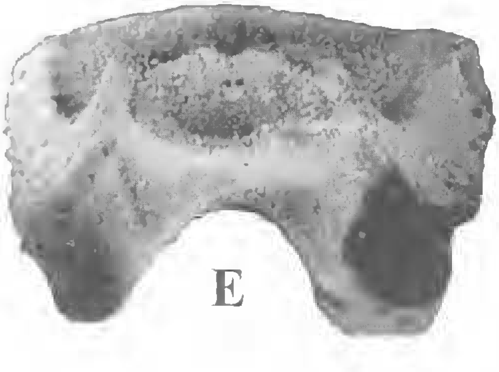


FIG. 24. A-C, *Calceolispongia abundans* Teichert, 1949, basal, posterior and A ray views of partial crown QMF38874, ×2.3. D,E, *Calceolispongia rubra* Teichert, 1949, proximal and distal facet views of 2nd brachial QMF38876, ×4.1.

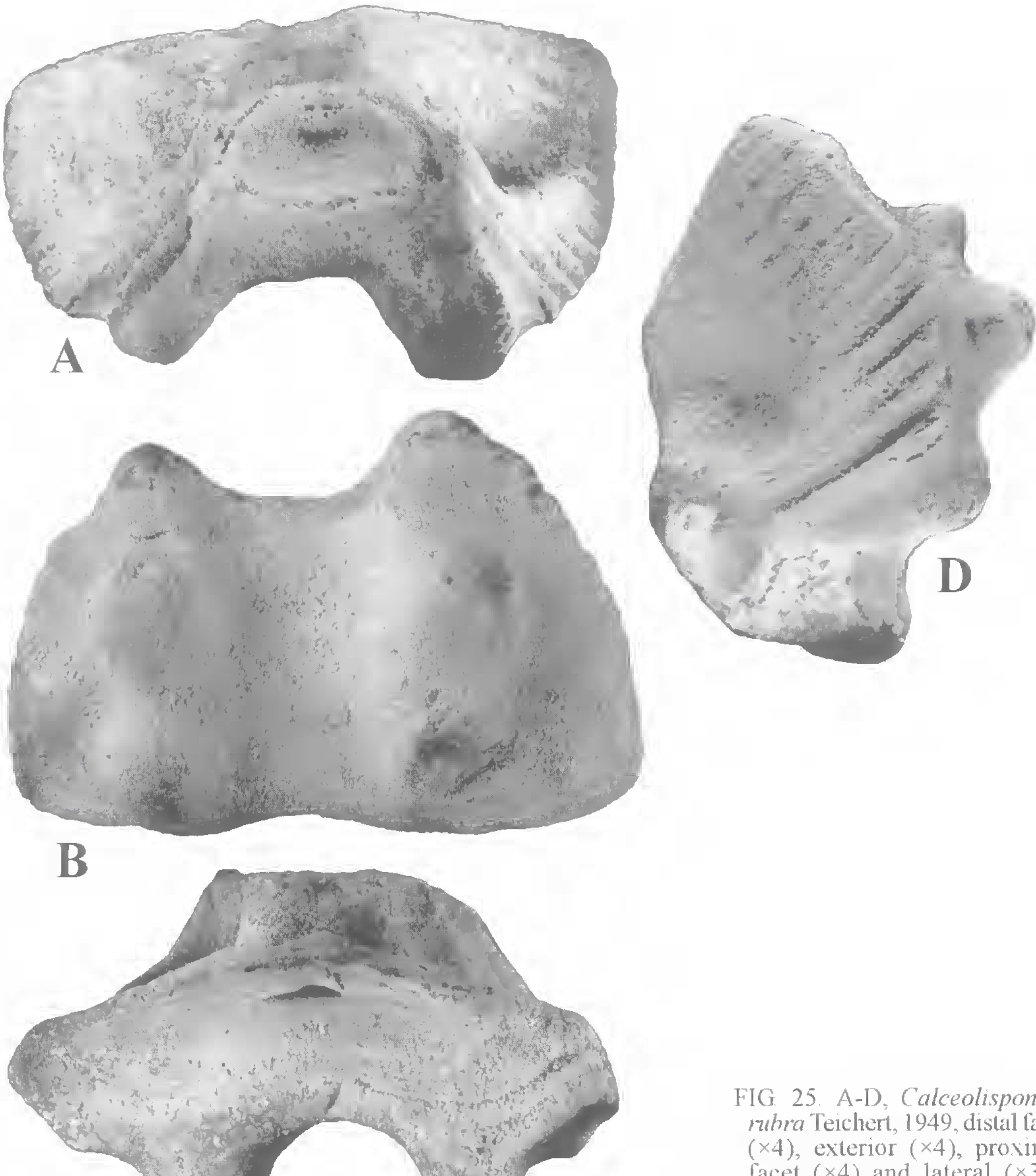


FIG. 25. A-D, *Calceolispongia rubra* Teichert, 1949, distal facet (×4), exterior (×4), proximal facet (×4) and lateral (×3.2) views of 2nd brachial QMF38878.

4th brachial. It was transported to the site of burial with loss of the stem and perhaps some of the distal parts of the arms. At the site of deposition some of the 1st to 4th brachials were disarticulated and moved into the visceral cavity as the specimen was buried. The silt and sand enclosing the partial crown and the associated disarticulated plates are compacted and slightly cemented. Most of the enclosing matrix is easily removed by wetting, brushing with a moderately stiff tooth brush and light scraping with a needle under the microscope.

Features not previously described on *C. abundans* are the ridges and grooves of the lateral ends of the 1st and 2nd brachials. The 1st ridge and groove are 1.7mm above the proximal end of the 1st brachial and the last is at the distal end of the 2nd brachial. Initial ridges and grooves are short and of low amplitude, whereas distal ones have higher amplitude. With the brachial in a living or near vertical position, the ridges and grooves are oriented nearly horizontally with a very gentle curvature, centrally convex upward. There are 7 ridges on the 1st brachial in 2.8mm, and 6 ridges in 2.7mm on the 2nd brachial. In lateral view, with the arms enclosed, they appear to interlock with false symplectic articulation.

Development of the ridges and grooves on the ends of the proximal brachials is known in other species of *Calceolispongia*, such as *C. lizziensis* (Willink, 1979b, pl. 9, fig. 18) and *C. spectabilis* (Teichert, 1949, pl. 19, fig. 40), as well as poteriocrinitoids such as *Spaniocrinus*, as described above. Most commonly the apparent interlocking occurs between apposing brachials and may extend along most of the arms of adjacent rays, such as in *Parastachyocrinus*. In these forms alternate brachials form the groove and ridges of 1 arm and the brachials of the adjacent arm form the counterparts to produce the interlocking fit. Webster & Lane (1967) referred to this as an 'interlocking structure' and interpreted it as adding strength to the enclosed crown. They also considered that this limited the movement of the proximal brachials below the arm girdle or constriction in the arms occurring immediately above the interlocking on the cromyocrinid *Moapacrinus*. The interlocking of adjacent brachials is structurally quite different from the ridge and groove development on individual brachials of *Calceolispongia*, although they may have served a similar purpose.

We suggest the structures in the calceolispongiids served as sliding guides for differential rotational movement of adjacent proximal brachials as the arms were opening and closing as well as guides for forming a close fit when the arms were entirely extended and were being tightly enclosed. A rotational movement of the arms above the transverse ridge of the radial facet occurred as the arms opened and closed. Thus gently curved ridges and grooves allowed a relatively smooth differential movement between laterally adjacent plates. The crinoid could flex 1 arm to a greater or lesser degree than the 2 adjacent arms. When the arms are flexed to a position where the 1st and 2nd brachials were not in lateral contact with the brachials of adjacent rays (Teichert, 1949, pl. 9, figs 1, 2), the ridges and grooves of one arm were not in contact with those of adjacent rays, but would have served as guides for proper positioning of the brachials as the arms enclosed.

In the enclosed position the ridges and grooves would have also restricted translational movement of the 2 proximal brachials parallel to the long axis of the arms. This would allow tensional forces (such as predators nipping the tips of the arms or accidentally hitting the arms while chasing prey) applied to the distal parts of the arms to be mitigated by the added strength of the 2 adjacent arms on the proximal 2 largest brachials. Depending upon the amount of tension, this could have resulted in retention of the 2 proximal brachials, the largest in the arm, when the distal brachials were lost. Retention of the proximal part would require regeneration of fewer brachials and thus less time and energy to replace the lost part of the food gathering network.

The enlarged proximal 2 brachials surrounded an expanded visceral cavity. We suggest that they served as a plated structure surrounding the tegmen in the enclosed position, while also serving as moveable arm bases. To accomodate expansion of a full gut tract, the 2 proximal brachials would have rotated outward. The ridge and groove structure would have allowed smooth expansion and contraction with a slight rotational movement of the proximal brachials. The nodes or blunt spines on the 2nd brachial would have served for protection analogous to tegmen spines. In the feeding position, the opened arms would have allowed some exposure of the visceral mass above the radials, covered only by the tissue of the tegmen.

Teichert (1949) described the nervous system of *Calceolispongia* as a series of fine canals on the inner side of the cup plates. He did not mention the dual entoneural canals of the brachials. From the radials there are 4 canals that pass into the first brachial on the oral side of the transverse ridge of the arm facet. On the distal cryptosyzygial facet with the 2nd brachial the 4 canals continue into the inner side of the 2nd brachial and as they come out on the distal side they merge into 2 canals continuing throughout the more distal brachials. The 2 very small entoneural canals are on the oral side of the centre of the transverse ridge of facets with muscular articulation and at the growth centre of brachials with cryptosyzygial articulation. First and 2nd brachials (QMF38875-38878) of *C. rubra* Teichert, 1949 from the Wandagee Sandstone (QML1222) show the canals (Fig. 24D,E, 25, 26A-D). The dual internal canals also occur in the brachials of *Jimbacrinus bostocki*. In *J. bostocki* they pass across the radial facet into the 1st brachial on the oral side of the transverse ridge. In the distal

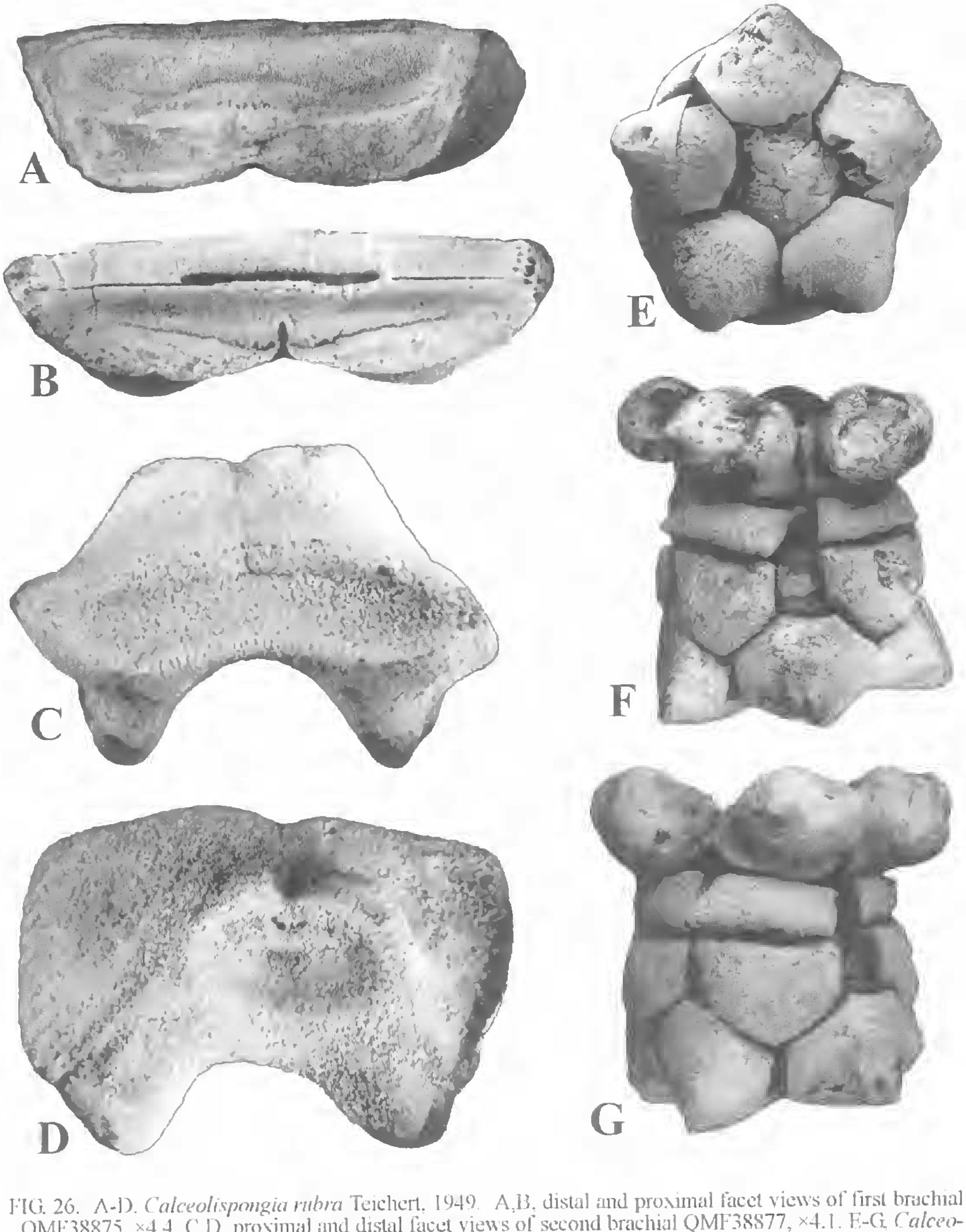


FIG. 26. A-D. *Calceolispongia rubra* Teichert, 1949. A,B, distal and proximal facet views of first brachial QMF38875, ×4.4. C,D, proximal and distal facet views of second brachial QMF38877, ×4.1. E-G, *Calceolispongia gerthi* Willink, 1979b, basal, posterior and D ray views of reconstructed crown GSQF13488, ×1.5.

brachials thereafter, there are dual canals as in *Calceolispongia*.

Calceolispongia gerthi Willink, 1979b
(Fig. 26E-G)

MATERIAL. GSQF13488a-r, 5 basals (13488a-e), 5 radials (13488f-j), 4 first brachials (13488k-n), and 4 second brachials (13488o-r) from the early Artinskian Berridale Formation, Rathbone's Quarry, Granton, Tasmania. Collected by S. Parfrey.

REMARKS. Willink (1979b) based the description of *Calceolispongia gerthi* on disarticulated second brachials. He recognised that the basals were not distinguishable from those of *C. diemenensis* and described and illustrated basals referred to as *C. gerthi-diemenensis*. No cups or crowns were reported for either species. All of the material came from the Crinoidal Zone on Maria Island.

The discovery of disarticulated plates from a single specimen in a thin shale between 2 limestone layers in the Berridale Limestone allowed the reconstructon of a partial crown including the first 2 brachials. Among the 5 basals, only the CD basal has a truncated distal end for reception of the anal plate, which was not recovered. Under the microscope the sutures of the basal and radial plates along the anal interseries were shorter than those between comparable plates in other interrays. Likewise, facets between the radials and 1st brachials of the C and D rays were shorter than those in other rays, and had a short gap on the end adjacent to the anal interray, allowing recognition of their positions within the cup. Facets of the 1st and 2nd brachials of the C and D rays were shorter and slightly twisted compared to those in other rays allowing easy recognition. The rest of the specimen was reconstructed around the C and D rays. The BC and DE basals are broken, but the pieces were glued together. Unfortunately the BC basal was also distorted by compaction and the DE basal was solution weathered. It is uncertain if they are in the correct positions or interchanged on the reconstruction. The AB and EA basals would not fit the sutures for the BC and DE, and are thus presumed to be in their correct positions. The third 1st brachial could fit on the E, A, or B radials, and thus its position, though correct within a ray, cannot be more precise. Likewise the 2 second brachials have been solution weathered and it is uncertain which, if either, fit the 1st brachial. The infrabasal circlet was not recovered.

The reconstructed partial crown is cylindrical and probably rested on the enlarged basals on the substrate with a runner or tether stem. The proximal side of the blunt spine projections is essentially horizontal, and the infrabasal circlet is not visible in side view, as it is downflaring or subhorizontal and confined to a shallow basal concavity. The radials are subvertical and the protruded knobs of the 2nd brachials are subhorizontal to slightly upflared in the enclosed position. When the arms were fully extended laterally the knobs would have rested against the apex area of the subjacent radial and 2 basals.

If *C. gerthi* lived elevated slightly above the substrate, the basal projections could have served as bumpers to keep the crown in a near upright position when tilted by currents or scavengers. The blunt spines on the basals along with the knobs of the 2nd brachials would help to prevent the arms getting into the sediment and ambulacral trackways from getting fouled when hit by scavengers or strong current surges. From the shape of the reconstructed cup it is most likely that *C. gerthi* rested on the substrate with a runner stem.

Calceolispongia sp.
(Fig. 27)

MATERIAL. One slab with 3 basals, anal, and numerous brachials, all external moulds, QMF39012 from QML518.

DESCRIPTION. Plates thickened, basals protruded into short double spine projecting out and upward, surface ornament coarse nodes and anastomosing ridges aligned towards spine tips. Anal pentagonal, with central rounded node. Brachials cuneate, concave longitudinally, strongly rounded transversely; ambulacral groove wide, deep V-shaped.

REMARKS. The plates of *Calceolispongia* sp. are part of a single specimen disarticulated by currents or scavengers leaving them in close association. Other plates are unknown, either not exposed or lost by weathering. The basals are similar in shape to *C. gerthi* and *C. diemenensis* (Willink, 1979b), except they have surface ornament in addition to the double spine. If these plates are from a fully grown individual, the specimen would have been small, cylindrical, and lived on the substrate with a runner stem. It probably represents a new species, based on the nodose to anastamosing ridge ornament, that evolved from *C. gerthi* or *C. diemenensis*. Lacking radials and proximal brachials it is left in open nomenclature and mentioned for completeness of the Condamine fauna.

FIG. 27. *Calceolispongia* sp., overlapping views of dislocated cup and arm plates, QMF39012, ×2.5.

Jimbacrinus Teichert, 1954

TYPE SPECIES. *Jimbacrinus bostocki* Teichert, 1954, from the Artinskian Cundlego Sandstone of WA; by original designation.

Jimbacrinus donnellyensis
Webster & Jell, 1992

Jimbacrinus donnellyensis Webster & Jell, 1992: 353, fig. 21.

REMARKS. The locality for *J. donnellyensis* was given as from the upper part of the Artinskian Bulgadoo Formation in the type section near Donnelly's Well (Webster & Jell, 1992). Because this is one of the few limestone environments above the Callytharra Formation in the Permian of WA the locality was deemed worthy of reinvestigation for additional information and more precise location. The yellow weathering limestone is a small lense, forming a weak bench at the base of the slope. QML1141. Collection yielded 45 crowns of *J. donnellyensis* (QMF39151-39195), 3 crowns of *Stomiocrinus merlinleighensis* (QMF39196-39198), 7 basals of *Calceolispongia* sp. (QMF39210-39216), 8 columnals of *Neocamptocrinus* sp. (QMF39202-39209), 2 radials of *Thaumatoblastus* sp. (QMF-39200, 39201) and 1 spine of *Archaeocidaris*? sp. (QMF39199). All specimens are in loose blocks or occur as free elements.

Metacalceolispongia gen. nov.

TYPE SPECIES. *Cymbiocrinus cherrabunensis* Webster & Jell, 1992 from the Wuchiapingian Cherrabun Member, Hardman Formation, WA.

ETYMOLOGY. Greek *meta*, between or change, and *Calceolispongia*, implying a derived form.

DIAGNOSIS. Bowl-shaped cup, thick inflated plates, apical pits, 1 anal, plenary radial facets, 2 primibrachs, 11 arms minimal incurl distally, brachials cuneate, muscular and cryptosyzygial paired brachials, pentagonal proximal columnals.

REMARKS. *Metacalceolispongia* differs from all other calceolispongiids by having more than 5 arms. It is similar to *Cymbiocrinus*, differing by having more than 10 arms, thick plates and a pentagonal stem proximally. It could have evolved from *Allosocrinus* by further branching of the arms or from *Calceolispongia* by branching of the arms and less protrusion of the basals.

Metacalceolispongia cherrabunensis
(Webster & Jell, 1992)

Cymbiocrinus cherrabunensis Webster & Jell, 1992:351, fig. 20.

DESCRIPTION. See description of *Cymbiocrinus cherrabunensis* Webster & Jell (1992: 351).

REMARKS. Webster & Jell (1992) commented that the 3rd arm on the C ray of *C. cherrabunensis* is atypical of *Cymbiocrinus* and noted the affinities to *Jimbacrinus*. Evaluation of *Cymbiocrinus* and the Calceolispongiidae within the Articulata lineage resulted in reassignment.

Family TRIBRACHYOCRINIDAE
Arendt & Willink, 1981

DIAGNOSIS. Cup globose, relatively large; infrabasals upflared, distal tips visible in lateral view; radial facets plenary; 1-4 anals; 12 or 20 arms; isotomously branching; cuneate brachials ramulate; brachial pairs with alternating muscular and cryptosyzygial articulation; stem relatively large, round in transverse section, with round lumen; may be very cirriferous close to cup.

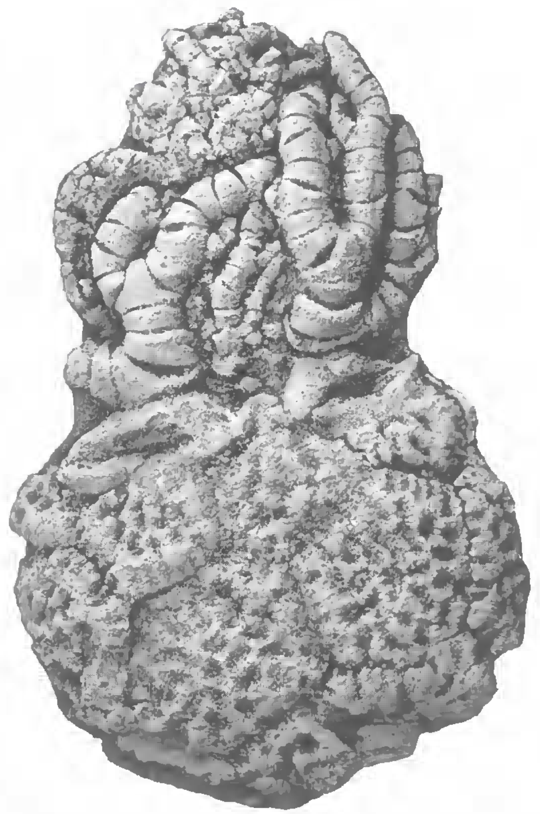


FIG. 28. *Tribrachyocrinus corrugatus* Ratte, 1885, B ray view of crown Z3256, ×2.3.

GENERA INCLUDED. *Tribrachyocrinus*, *Meganotocrinus* and *Nowracrinus*.

REMARKS. *Tribrachyocrinus* was assigned to the Sundacrinidae on the basis of arms developed in 3 rays (Moore & Laudon, 1943) and made the monotypic type of the Tribrachyocrinidae by Arendt & Willink (in Arendt, 1981). *Meganotocrinus* was questionably assigned to the Ampelocrinidae and *Nowracrinus* was considered incertae sedis (Willink, 1979b). Except for the non-development of arms in 2 rays and a larger number of anals there is little difference between *Tribrachyocrinus* and *Meganotocrinus* or *Nowracrinus*. *Nowracrinus* differs from *Meganotocrinus* by stellate crenulations extending across plate boundaries. The tribrachyocrinids differ from all other Ampelocrinida by the development of ramules instead of pinnules and the large transversely circular stem. They were an intermediate or upper tier feeder, adapted to carbonate and clastic substrates in higher latitudes.

Tribrachyocrinus M'Coy, 1847

TYPE SPECIES. *Tribrachyocrinus clarkii* M'Coy, 1847 from Roadian or Wordian sediments in the Maitland district, NSW; by original designation.

Tribrachyocrinus corrugatus Ratte, 1885 (Fig. 28)

MATERIAL. TMZ3256, from the Malbina Formation, late Artinskian, Storm Bay Sheet 8411, 1:100,000, grid reference 773 348, Tasmania. Collected by Andrew Rozefelds, Max Banks and Noel Kemp.

DESCRIPTION. Crown small, 42mm long, 26.6mm wide, all cup plates with coarse corrugate ornament. Part of infrabasals, basals, A-C radials, radianal, 3rd anal, parts of A and C ray arms preserved in flattened plane. Radial facet plenary. First primibrach wedge-shaped, tapering distally. Axillary 2nd primibrach triangular, distal tip separating facets for widely diverging 1st secundibrachs. Axillary 2nd or 3rd secundibrach, shaped like axillary primibrachs. Both branchings isotomous. All distal brachials cuneate, uniserial, straight to weakly concave longitudinally, strongly convex transversely, with smooth external surface. Large ramule or small arm on every 2nd tertibrach, alternating sides of main arm for next 4-6 brachials, unknown thereafter. In A ray first ramule on 3rd tertibrach, 2nd ramule on 5th tertibrach on 1/2 ray adjacent to C ray. In 1/2 ray adjacent to D ray 1st ramule on 2nd tertibrach, 2nd ramule on 5th tertibrach. Thereafter ramules every other tertibrach. Brachials paired, musculature articulation on branching facets and after ramules alternating with cryptosyzygial.

REMARKS. The small crown is crushed by compaction. It is the first crown of this species known with well-preserved arms of 2 rays. The description of the arms supplements the excellent cup analysis and description of *T. corrugatus* by Willink (1979b).

Tribrachyocrinus granulatus Etheridge, 1892 (Fig. 29)

MATERIAL. TMZ3258, from the Malbina Formation, late Artinskian, Storm Bay Sheet 8411, 1:100,000, grid reference 773 348, Tasmania. Collected by A. Rozefelds, M. Banks and N. Kemp.

REMARKS. The cup has a 1.8mm diameter hole drilled through the left central part of the large A-C basal plate in the centre of the flattened specimen. Non-predatory drill holes in the tegmen plates of Early Carboniferous camerate crinoids were described by Baumiller (1990) and epizoan pits on cup, tegmen and arm plates of early and middle Palaeozoic crinoids were reported by Brett (1978, 1985). To our knowledge, no predatory drill holes through cup plates of Palaeozoic crinoids have been reported. The hole was there prior to deposition, is filled with the surrounding fine silty clay matrix and has a compaction fracture through the plate crossing the right edge of the hole. Burial was rapid as no overgrowths or abrasion occurred. Solution weathering has destroyed part of the surface calcite of most exposed plates. Scavengers have not disarticulated the cup plates and the degree of articulation of the parts of the arms present cannot be determined because of matrix cover. A small, gastropod, *Peruvispira* sp., 3.7cm away from the cup, is not known to be carnivorous (A. Cook, pers. comm., 1998) and is not thought to have been associated in a coprophagous relationship with the specimen.

FIG. 29. *Tribrachyocrinus granulatus* Etheridge, 1892. C ray view of cup with drill hole in radianal. Z3258, ×2.6.

Willink (1979b) considered *T. granulatus* uninterpretable and recommended suppression

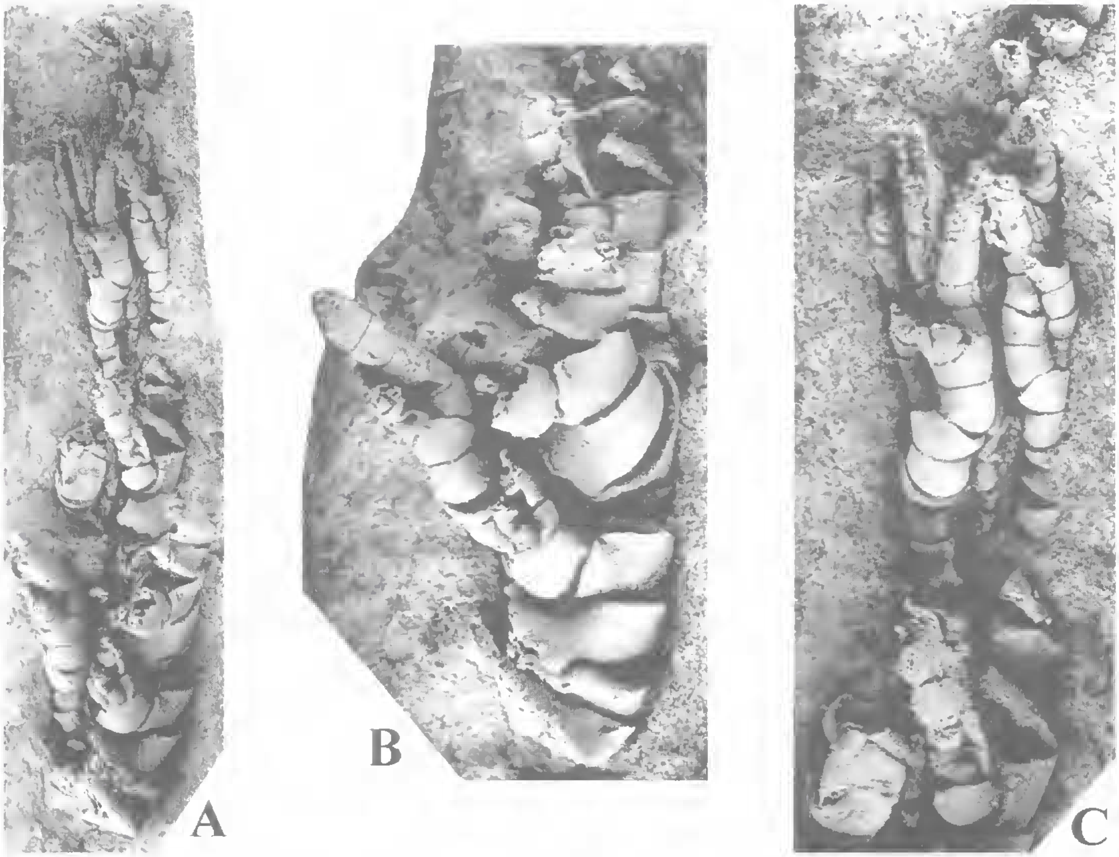


FIG. 30. *Tribrachyocrinus*? sp. arm fragment, A-C, lateral view of whole specimen (×1.7), enlarged proximal (×2.4) and distal (×3.1) views of QMF38898.

of the species because no additional material had been found. He also considered *T. granulatus* as possibly representative of *T. rattei* Willink, 1979. If such were proven *T. granulatus* would have precedence. *T. rattei* has aligned nodes coalescing into ridges. *T. granulatus* has only nodes, which may show alignment, therefore we accept both species.

Tribrachyocrinus? sp., arm fragment
(Fig. 30)

MATERIAL. QMF38898 from QML806.

DESCRIPTION. Arm large, 60mm long (incomplete), branching of indeterminate type on 6th brachial, may branch again distally. Brachials large, (proximal brachial 3.2mm long, 6.7mm wide, 7mm deep), uniserial, moderately cuneate, concave longitudinally, strongly convex transversely, large ramule given off on every other brachial on opposite sides of arm (2 ramules per 4 brachials). Articular facet of proximal brachial with large rounded transverse ridge; narrow crescent-shaped outer margin with deep ligament pit adjacent to transverse ridge; muscle areas large, narrowing distally. Ramulars moderately cuneate, straight to weakly convex longitudinally, strongly convex transversely. Ramules branching on ramular 4 or 5, may branch again on secundiramular 2, and tertiramular 2; may give off small unbranched ramules of pinnular size. Brachials paired with muscular articulation where branching or a ramule is given off alternating with cryptosyzygial articulation where no branching occurs.

REMARKS. The branching pattern of the ramules is similar to that of *Tribrachyocrinus corrugatus* above the branching on the second secundibrach. The branching of the ramules may represent a specific difference. The branching also resembles that of the Silurian flexible *Cholocrinus obesus* (Angelin, 1878), the Early

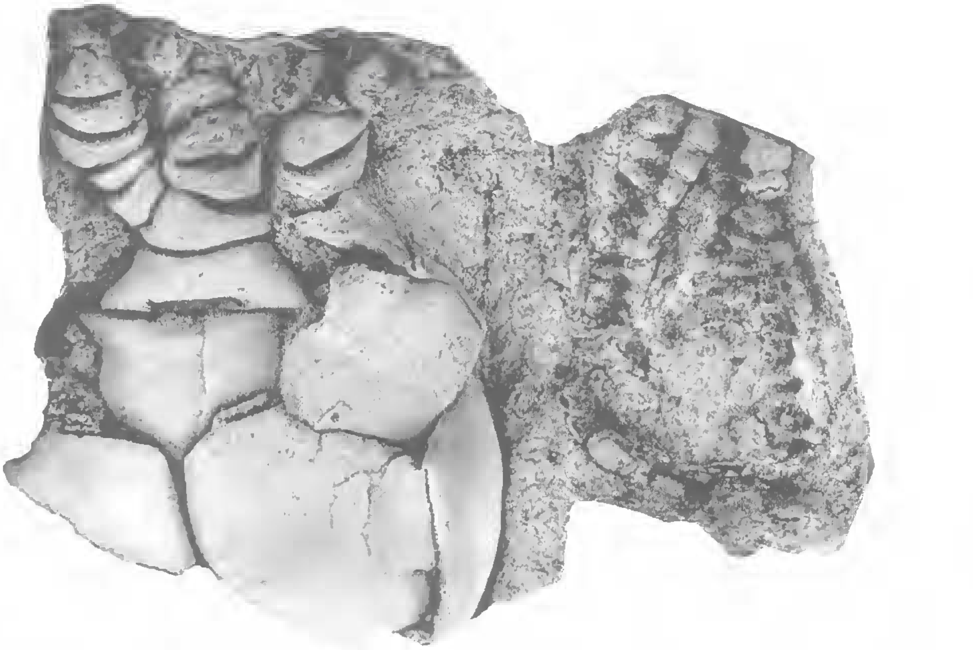


FIG. 31. *Meganotocrinus princeps* (Etheridge, 1892), lateral view of abnormal crown BME68151, ×1.7.

Carboniferous cyathocrinitid *Barycrinus asteriscus* Van Sant, 1964 and flexible *Onychocrinus exsculptus* Lyon & Casseday, 1860. There is no indication of patelloid processes on either brachials or ramulars and the articular facet of the 1st brachial is of a form common to many poteriocrinitids.

Meganotocrinus Willink, 1979

TYPE SPECIES. *Phialocrinus princeps* Etheridge, 1892 from Artinskian Muree Sandstone Member, Branxton Formation, NSW; by original designation.

Meganotocrinus princeps (Etheridge, 1892) (Fig. 31)

MATERIAL. BME68151, Middle Permian, from an unknown locality in Queensland or NSW.

REMARKS. A request for loan of the type specimen of *Poteriocrinites smithi* resulted in not only the plasticine type of *P. smithi*, but, the external mould of a partial crown of *Meganotocrinus princeps* with an identification label of *P. smithi*, from the Gympie Beds, Stanwell, near Rockhampton. The specimen is part of the Dunstan Collection, purchased by the British Museum, July 1935. There is obviously a mixup in the locality and identification of the specimen.

This specimen of *M. princeps* is an external mould of parts of 3 rays of an abnormal cup and proximal brachials, with associated, but not attached, distal parts of 3 or 4 arms. It is embedded in a volcaniclastic matrix. Permian strata in the Stanwell area are the Early Permian Youlambie Conglomerate and early Late Permian Dinner Creek Conglomerate. Permian volcaniclastic deposits are present in and SE of the Rockhampton area, about 25-45km E of Stanwell. Other Permian volcaniclastics and sedimentary deposits are present 20-30km W and SW of Stanwell. Thus the specimen could be from the Stanwell or Rockhampton area. All reported localities of *M. princeps* are in NSW (Willink, 1979b).

The abnormality occurs on one of the radials, which lacks the development of the arm and terminates in a distally projected wide V-shaped extension. The 1st primibrachs of the 2 adjacent arms partly overlap the radial, the one on the right more than that on the left. There is no indication of a radial facet, nor of any injury. This appears similar to B and E radials in *Tribrachyocrinus* where no arm is developed. If the 3 basals were not exposed the specimen would have been assigned to *Tribrachyocrinus*. It is interpreted as a genetic defect and is illustrated to show the abnormality, but may also indicate the close

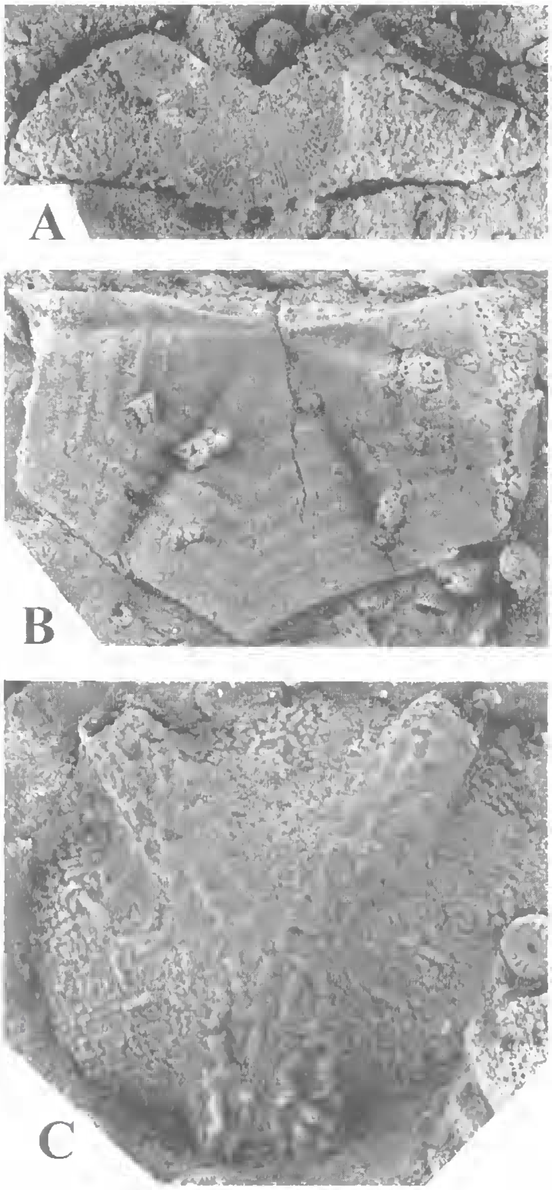


FIG. 32. *Nowracrinus ornatus* Willink, 1979. A, distal facet view of primibrachial QMF39020, ×2.8. B, internal view of radial QMF39015, ×2.4. C, external view of basal QMF39014, ×3.4.

relationship between *Tribrachyocrinus* and *Meganotocrinus*.

Nowracrinus ornatus (Etheridge, 1892)
(Figs 32, 33)

Tribrachyocrinus ornatus Etheridge, 1892: 94, pl. 19.
Nowracrinus ornatus (Etheridge); Willink, 1979a: 124, figs 3-6f.

MATERIAL. Basal, QMF39014, radial QMF39015 primibrachs, QMF39019, 39020 and columnals QMF39016-39018, 39021, 39076, 39077 from QML1247.

DESCRIPTION. This description only adds or alters that of Willink (1979a). Pluricolumnal heteromorphic, pentagonal in transverse section. Noditaxis N3231323 minimal, may be more complex. Columnals large, pentagonal nodal 10.1mm diameter, c. 1mm thick; internodals subround to pentagonal, weakly pentastellate, 8.5mm diameter, <0.7mm thick. Nodal latus narrow, strongly protruded, relatively sharp, rounded; internodal latus similar. Facets with narrow crenularium parallel to pentagonal sides of columnal, crenulae and culmina coarse, straight sided, slightly longer at angles of columnal, otherwise equal length. Areola narrower to slightly wider than crenularium. Lumen large, subcircular to pentagonal, parallel to outline of columnal. Symplexy articulation. Nodals with 5 cirri. Cirral facet elliptical, long axis parallel to columnal facets, with small central axial canal.

REMARKS. Combination of the intraplate crenulations and nodose to vermiform ornamentation are the distinctive features of cup plates of *N. ornatus*. Columnals lack surface ornament but the pentagonal and pentastellate outline combined with distinctive facets could be used for correlation in absence of the cup plates. All columnals are slightly to moderately distorted from compaction.

Family INCERTAE SEDIS

Tasmanocrinus Willink, 1979

TYPE SPECIES. *Tasmanocrinus mariensis* Willink, 1979, from Sakmarian strata on Maria Island, Tasmania; by original designation.

Tasmanocrinus sp.
(Fig. 34)

MATERIAL. TMZ3259, from the Malbina Formation, late Artinskian, Storm Bay Sheet 8411, 1:100,000, grid reference 773 348, Tasmania. Collected by Andrew Rozefelds, Max Banks, and Noel Kemp.

DESCRIPTION. Crown cylindrical, 24.5mm long, 9mm wide (incomplete, plates slightly disassociated). Cup conical, 3.7mm long, crushed. Radials 4 or 5, 3.7mm long, 3.2mm wide, subvertial longitudinally, gently convex transversely, proximal end weakly convex, distal end with peneplenary radial facets. Arms 10? Brachials cuneate, strongly convex transversely, with open V-shaped ambulacral groove.

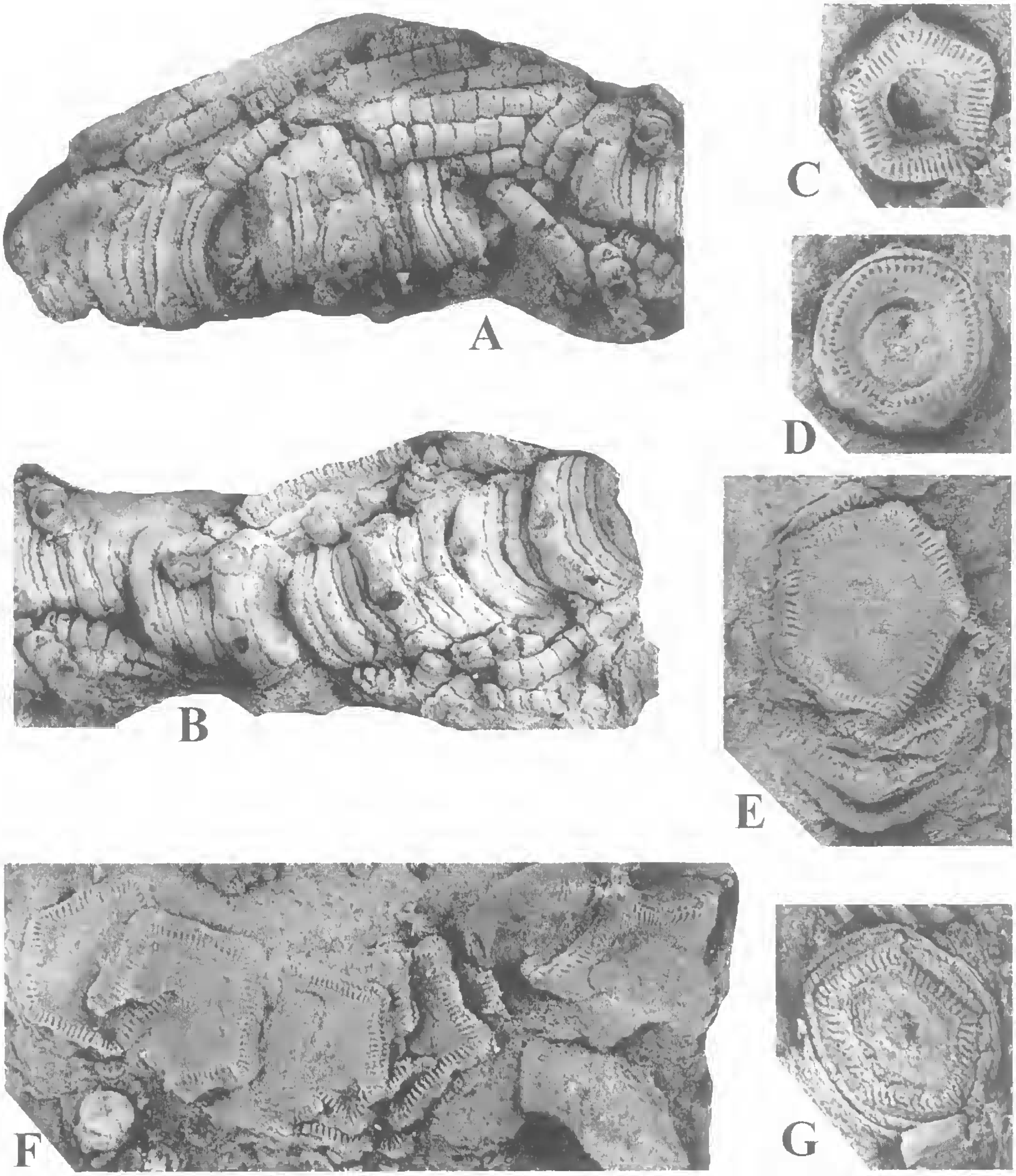


FIG. 33. *Nowracrinus ornatus* Willink, 1979. A,B, overlapping views of crushed pluricolumnal, QMF39018, ×2.8. C, facetal view of columnal QMF39077, ×4.2. D, facetal view of columnal QMF39021, ×4.2. E, facetal view of slightly disarticulated pluricolumnal QMF39016, ×3.3. F, facetal view of slightly disarticulated pluricolumnal QMF39017, ×3.4. G, facetal view of columnal QMF39076, ×4.4.

Cryptosyzygial and muscular articulation on alternating pairs of brachials distally. Pinnules stout. Stem pentagonal, 4mm attached to cup, 36mm unattached, heteromorphic; noditaxis N3231323. Columnals pentalobate, lobed to noded on petals, with strongly convex latus. Cirri close to cup, probably 5 per nodal. Cirrals short, round transversely, with convex latus.

REMARKS. This is the second specimen of *Tasmanocrinus* and probably represents a new

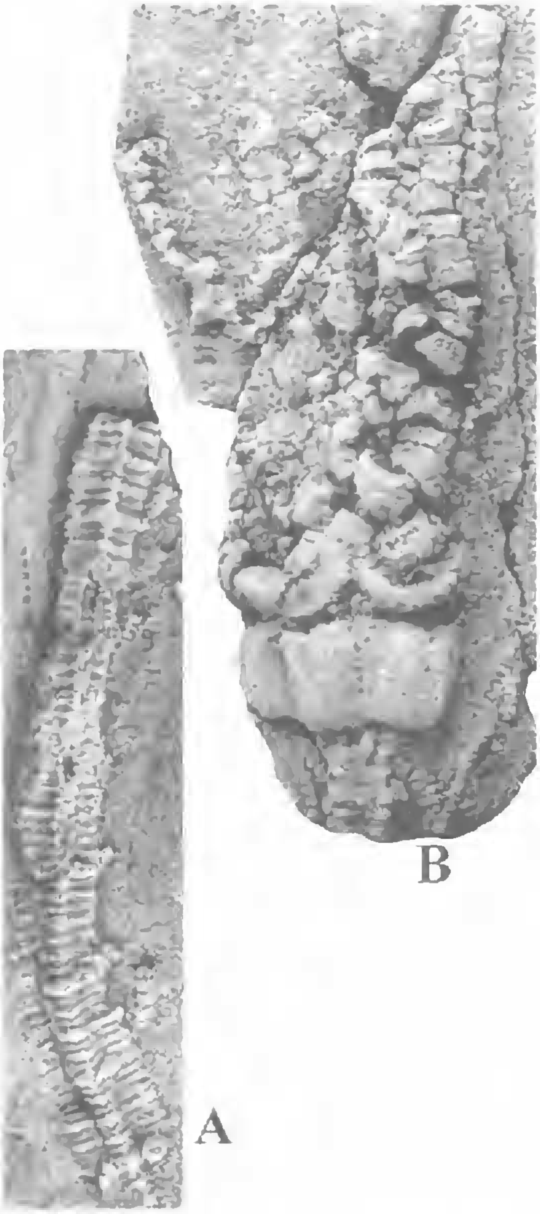


FIG. 34. A,B, *Tasmanocrinus* sp., lateral views of partial proximal stem and crown. Z3259, ×3.3.

species. It is crushed with plates slightly to moderately disassociated. Weathering and recrystallisation have destroyed facets on most exposed surfaces and ornamentation. A weak line of nodes or granules parallel to the intraradial sutures may be the remnant of coarser nodes similar to the aligned nodes on *T. mariensis* Willink, 1979. The elongate conical cup was possibly cryptodicyclic with the basals and infrabasals not visible in lateral view whereas the basal circlet formed a visible part of the cup of *T. mariensis*. In the radial circlet 3 plates are exposed and 2 are discernible through the thin layer of silt and clay covering the opposite side of the specimen. Willink (1979a) described *Tasmanocrinus* as having 3 radials bearing arms, a 4th radial lacking the distal end and a 5th plate as a radial-like anal. This specimen does not provide additional information concerning the uncertainty of the 4th radial. Only 2 of the 1st primibrachs are visible among the somewhat disarticulated arm plates.

Family affinities of *Tasmanocrinus* are uncertain. Cup shape has affinity with the Corythocrinidae. If there are only 3 arms it could be related to *Tribrachyocrinus*, but the arms are pinnulate not ramulate. The pentagonal stem, cirriferous close to the cup, is similar to some Ampelocrinidae. Brachial and columnal articulation show affinity with the Articulata and the peneplenary facets are unique within the Ampelocrinida.

Order ISOCRINIDA Sieverts-Doreck, 1952
Family ISOCRINIDAE Gislén, 1924

Archaeoisocrinus gen. nov.

TYPE SPECIES. *Archaeoisocrinus occiduaustralis* from the middle Artinskian Cundlego Sandstone, Jimba Jimba Station, WA.

ETYMOLOGY. Greek *arche*, beginning, old, or primitive, and *Isocrinus*; refers to the beginning of the isocrinids.

DIAGNOSIS. Crown small, cylindrical, with arms enclosed. Cup discoidal, cryptodicyclic, infrabasals and basals in deep basal cavity, covered by proximal columnals; radials form base and cup wall; no anal or anal notch in cup. Radial facets plenary; wide gape between radials and 1st primibrach. Pentameral symmetry. Arms 10, branching isotomously on 2nd primibrach; brachials cuneate uniserial, with small dual internal entoneural canals, with 1 pinnule on long side of brachial above primibrachs. Brachial articulation alternating between oblique muscular and cryptosyzygial. Stem pentalobate; columnals thin, with strongly rounded convex latus.

REMARKS. *Archaeoisocrinus* differs from all other isocrinids, based on cups, in that the basals are within the basal cavity, and not visible in lateral view. *Archaeoisocrinus* is the oldest genus of the Isocrinidae, evolved from an ampelocrinid, possibly *Halogetocrinus*, in the Early Permian by

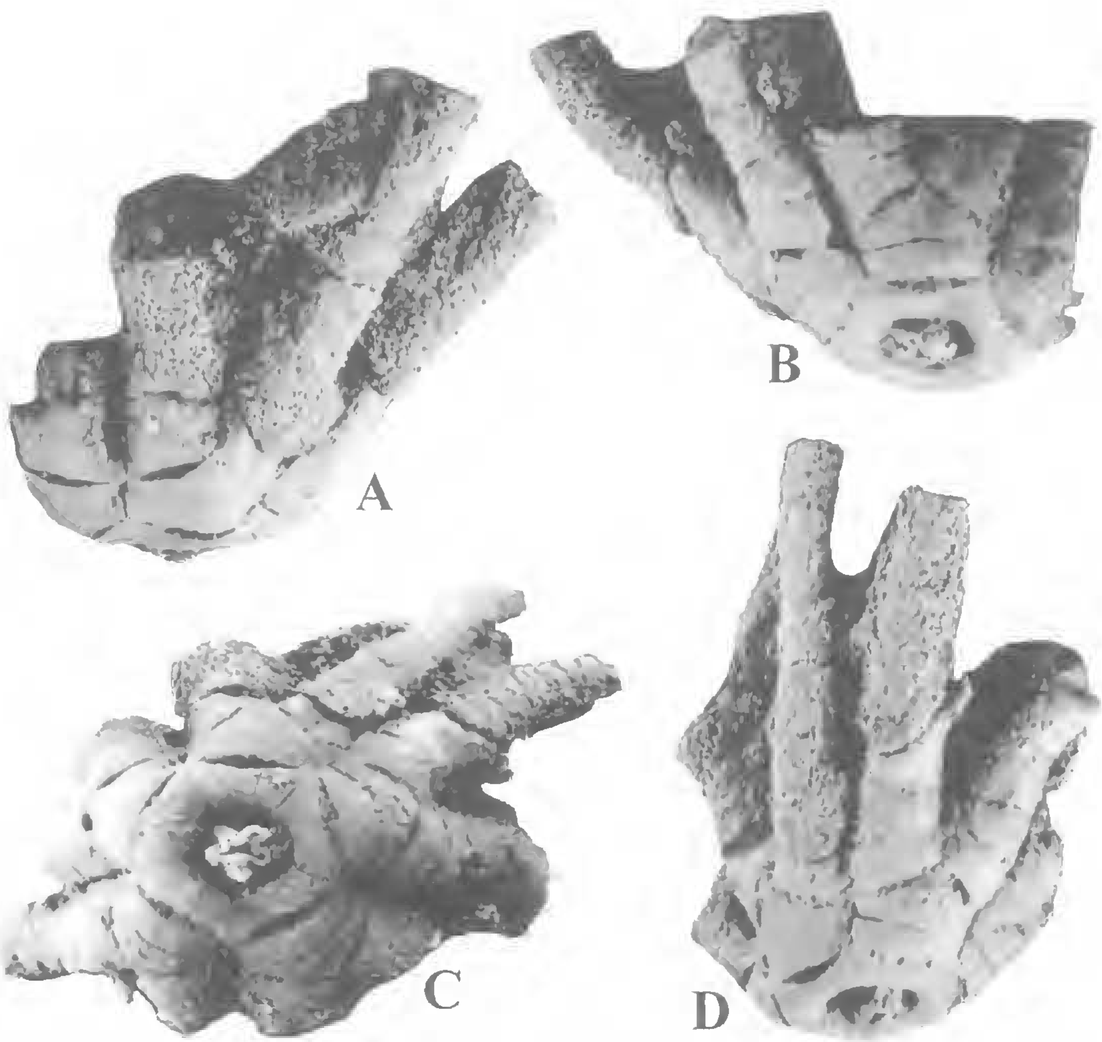


FIG. 35. A-D, *Archaeoisocrinus occiduaustralis* sp. nov. 3 lateral (A,B,D) basal (C) views of crown QMF38879, ×5.

removal of the anal plate from the cup and restriction of the basals to the basal invagination.

Previously, isocrinids were reported to range from Early Triassic to the Recent, with the Early Triassic specimens consisting of poorly preserved columnals lacking details of the articular facet (Rasmussen in Moore & Teichert, 1978). The middle Artinskian occurrence of *A. occiduaustralis* extends the range of the isocrinids back approximately 30 m.y.

Archaeoisocrinus occiduaustralis sp. nov.
(Figs 35, 36)

ETYMOLOGY. Latin *occidens*, western, and *australis*, southern.

MATERIAL. HOLOTYPE: QMF38879 from a nest of *Jimbacrinus bostocki* Teichert, 1954, from the Cundlego Sandstone on Jimba Jimba Station, WA. Slab found by Kevin Davy, Chris Johnston, and Tom Witherspoon and specimen found in preparation by Scott Vergiels. Crown retains the proximal 3 columnals, proximal part of all 10 arms, and medial parts of 2 arms.

DIAGNOSIS. As for genus.

DESCRIPTION. Crown small, cylindrical, with arms enclosed, 11.5mm long (incomplete), 9.6-16.7mm wide (13.1mm av. with arms partly opened). Cup discoidal, 0.8mm long, 4.2-4.5mm wide, with deep basal cavity, unornamented, with pentameral symmetry, without anal series in cup,

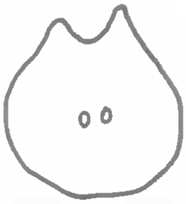


FIG. 36. *Archaeoisocrinus occiduaustralis* sp. nov., camera lucida drawing of distal facet of 9th secundibrach showing dual entoneural canals, QMF38879. ×20.

without anal notch on tip of indeterminate posterior radials, cryptodicyclic. Infrabasals? and basals within basal cavity, not visible in lateral or aboral views, covered by proximal columnals. Radials large, 1.4mm long (minimum), 2.6mm wide, strongly convex longitudinally, gently convex transversely, with proximal end in basal cavity, with medial part forming base of cup, distally gently upflared. Radial facet plenary, sloping down outward, 68° from horizontal, with large deep outer ligament pit, narrow outer marginal area. Large gape between radial and 1st primibrach. First primibrach 0.8mm long, 2.6mm wide on proximal end, 3.1mm wide on distal end, slightly convex longitudinally, moderately convex transversely. Axillary 2nd primibrach large, 1.3mm long, 3.2mm wide, slightly convex longitudinally, moderately convex transversely. All secundibrachs except 1st and 2nd moderately cuneate proximally, less cuneate distally, gently convex longitudinally, strongly convex transversely, nearly circular in transverse section, with single pinnule on long side; small dual entoneural canals circular in transverse section, centrally located; ambulacral groove small, V-shaped. First secundibrach rectilinear, 0.9mm long, 2.1mm wide. Second secundibrach small, nearly resorbed?, externally lens-shaped, restricted to middle of arms, 0.2mm long, 1mm wide. Third secundibrach cuneate, 1.6mm long on long side. 0.7mm long on short side, 2.1mm wide. Branching isotomous on 2nd primibrach in all rays, 10 arms, no distal branching on preserved arms. Straight muscular articulation between radials and primibrachs. Oblique muscular articulation between axillary 2nd primibrach and 1st secundibrach and between 3rd and 4th secundibrachs. Syzygial articulation between 1st and 2nd primibrachs and between 1st and 2nd, and 2nd and 3rd secundibrachs. Cryptosyzygial and muscular articulation on alternating pairs of brachials distally. Cryptosyzygial facet with faint culmina and crenellae on outer half of facet, radiating from entoneural canal. Stem pentalobate, facet not preserved. Columnals with strongly convex latus.

REMARKS. This delicate specimen is preserved with the arms slightly splayed around a sandstone matrix. The proximalmost columnals are distorted, masking the articular facet. Distal parts of the stem and arms are lacking.

ACKNOWLEDGEMENTS

We sincerely appreciate the support of Don Mackenzie, Alex Cook and Bev Webster in field investigations that recovered many of the specimens described herein. Loan of specimens by the Queensland Geological Survey (through Sue Parfrey), Geological Survey of Western Australia, and Tasmanian Museum and Art Gallery are gratefully acknowledged. We are grateful to the managers of Williambury, Wandagee, Cherrabun, Carey Downs and Middalya Stations for access to collecting localities on their properties. Parks and Wildlife Service, granted access for collection of some Tasmanian specimens. Larry Davis provided some references. Paul Avern processed photographs. This project was supported by the National Geographic Society Grant 5982-97. GDW extends his appreciation to Washington State University for granting professional leave and to the Director of the Queensland Museum for use of facilites and office space during prosecution of this project. The reviews of Tom Baumiller and Gary Lane are kindly acknowledged.

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APPENDIX 1

Queensland Museum localities referred to in text.

QML518 - Late Artinskian Condamine Beds, S side Lucky Valley Creek, Elbow Valley area, SW of Warwick, SE Qld. Magellan GPS coordinates 28°22'31"S, 152°08'19"E.

QML757 - Late Sakmarian or early Artinskian Callytharra Formation, N side of bladed track from Callytharra Homestead to Byro Homestead in W most exposures 1.5km W of type section S of Wooramel River, WA. 25°52'30"S, 115°29'E. Wooramel Sheet SG50-5, 1966.

QML758 - Late Sakmarian or early Artinskian Callytharra Formation, N side of bladed track from Callytharra Homestead to Byro Homestead as track enters dry wash tributary to Wooramel River, lowermost fossiliferous shale and marl capped by limestone in lower fossiliferous unit. Type section of Callytharra Formation. 25°52'30"S, 115°30'05"E, Glenburgh Sheet SG50-6, 1963.

QML759 - Late Sakmarian or early Artinskian Callytharra Formation, second fossiliferous shale and marl capped by limestone in type section of Callytharra Formation. South side of track and stratigraphically higher than QML758.

QML772 - Wuchiapingian Cherrabun Member of Hardman Formation; bench in lower slope below cliff 0.5-1.0km NNW of type section, Millyit Range; GR767877 Crossland Sheet SE51-16, 1977, WA. Magellan GPS coordinates 19°10'45"S, 125°32'35"E.

QML806 - Late Permian, Flat Top Formation, Back Creek Group; halfway up small rise, 1.3 km E on Uncle Tom road from Leichardt Highway, S of Banana, Queensland. Coll. A. Cook & M. Wade.

QML859 - Wandrawandian Siltstone; Point Upright, wavecut platform below lighthouse, Uladulla, NSW.

QML1141 - Middle Artinskian Bulgadoo Shale, upper part of type section SE of Donnelly's Well, Williambury Stn, WA. Magellan GPS coordinates 24°05'45"S, 115°05'40"E.

QML1145 - same as QML772.

QML1146 - Wuchiapingian Cherrabun Member of Hardman formation; bench in lower slope below cliff, Millyit Range, WA. Magellan GPS coordinates 19°10'28"S, 125°32'26"E.

QML1217 - Late Artinskian, basal massive sandstone of the Wandagee Sandstone, exposed in type section along the Minilya River, Wandagee Station, WA. Magellan GPS coordinates 23°44'20"S, 114°25'02"E.

QML1232 - Early Artinskian, upper part of Callytharra Formation, E limb of Gooch Range, W side of valley, E facing slope, S of Minilya-Lyndon road, up small drainage just S of where bladed road turns E to cross valley, WA. Magellan GPS coordinates 23°54'22"S, 114°56'54"E.

QML1233 - Float in limestone below QML1232.

QML1237 - Early Artinskian, upper part of Callytharra Formation, lower crinoidal rich zone, N side of Minilya-Lyndon Road, flat below slope, 50m SE of ridge, E limb of Gooch Range, WA. Magellan GPS coordinates 23°53'48"S, 114°56'48"E.

QML1240 - Early Artinskian, upper part of the Callytharra Formation, top of first bench nearest road, N side of Minilya-Lyndon road, E limb of Gooch Range, WA. Magellan GPS coordinates 23°53'41"S, 114°56'35"E.

QML1247 - Kansas Beds, Early Permian, Artinskian; roadcut and quarry on W side of cut at top of first hill on Blackwells Road, 0.8km W of junction with Highway A10. Blackwells Road is 14km S of junction A10 and B26, Yolla, Tasmania. Coordinates 83.25 35.80 Burnie Sk55-3, 1973.

GSWAL119377 - Artinskian, Billidee Formation, 4th limestone, Australian Map Grid coordinates Zone 50, 326340E, 7296860N, S of Mt Sandiman sheds. Coll. A.J. Mory.

APPENDIX 2

List of described Permian crinoid taxa from stratigraphic units of Western Australia, Queensland, New South Wales and Tasmania.

Cherrabun Member, Hardman Formation, Wuchiapingian, WA.
- *Neocamptocrinus millyitensis* Webster & Jell, 1992
- *Metacalceolispongia cherrabunensis* (Webster & Jell, 1992)

Wandagee Sandstone, late Artinskian, WA.
- *Calceolispongia abundans* Teichert, 1949

Cundlego Sandstone, middle Artinskian, WA.
- *Archaeoisocrinus occiduaustralis* gen. et sp. nov.

Billidee Formation, early Artinskian, WA.
- *Dichocrinus*? sp.

Callytharra Formation, late Sakmarian to early Artinskian, WA.
- *Neocamptocrinus*? sp.
- *Glaukosocrinus middalyaensis* sp. nov.
- *Parabursacrinus granulatus* Wanner, 1949
- Timorechinid gen. indet.
- Poteriocrinitid indet., arms 1
- Poteriocrinitid indet., arms 2
- Poteriocrinitid indet., arms 3
- *Loxocrinus booni* Marez Oyens, 1940
- *Loxocrinus* sp. 1
- *Loxocrinus* sp. 2
- *Prophyllocrinus* sp. 1
- *Prophyllocrinus* sp. 2
- *Prophyllocrinus* sp. 3
- Sagenocrinit id indet.
- *Platycrinites halos* sp. nov.
- Platycrinitid indet., columnals
- *Necopinocrinus tycherus* gen. et sp. nov.
- *Eidosocrinus condaminensis* gen. et sp. nov.
- *Pedinocrinus*? *nodosus* sp. nov.
- Stellarocrinid? gen. et sp. nov.
- *Spaniocrinus geniculatus* sp. nov.
- *Sundacrinus medius* sp. nov.
- *Moapacrinus cuneatus* sp. nov.
- *Eoindocrinus praecontignatus* Arendt, 1981
- *Calceolispongia* sp.
- Poteriocrinitid indet., arm fragment 1
- Poteriocrinitid indet., arm fragment 2
- Poteriocrinitid indet., arm fragment 3

Flat Top Formation, Wordian, Qld.
- *Auliskocrinus*? *bananaensis* sp. nov.
- *Tribrachyocrinus*? sp., arm fragment

Condamine Beds, latest Artinskian or early Roadian, Qld.
- *Neocamptocrinus* sp. nov.

Catherine Sandstone, late Artinskian, Qld.
- *Neocamptocrinus catherinensis* sp. nov.

Unknown stratigraphic unit, late Artinskian or early Roadian, Qld.?
- *Meganotocrinus princeps* (Etheridge, 1892)

Berridale Limestone, early Artinskian, Tas.
- *Calceolispongia gerthi* Willink, 1979

Kansas Beds, early Artinskian, Tas.
- Order indet., basal and radial plates
- *Nowracrinus ornatus* (Etheridge, 1892)

Malbina Formation, late Artinskian, Tas.
- *Tribrachyocrinus corrugatus* Ratte, 1885
- *Tribrachyocrinus granulatus* Etheridge, 1892
- *Tasmanocrinus* sp.

Wandrawandian Siltstone, late Artinskian, NSW.
- *Anaglyptocrinus willinki* gen. et sp. nov.